Advantages of Aliphatic Polyketones in Automotive Applications

ITB Automotive Energy Storage Systems Conference

Cary A. Veith, PhD
President, Esprix Technologies
March 1, 2017
Discussion Topics

- Background of Esprix Technologies
- Light-weighting Trend in Automotive
  - What’s required for Auto Energy Systems?
    => Good chemical resistance, mechanical and transport properties
- Overview of Aliphatic Polyketone (PK)
- Ketoprix™ PK Properties
  - Mechanical
  - Chemical Resistance
  - Fuels Permeability
  - Thermal and Electrical Conductivity
- Other Applications
- Summary and Conclusions
Who is Esprix Technologies?

Esprix is a private, specialty chemical & performance products company

Company Values:
- Practice Safety in Everything We Do
- Act with Integrity
- Demonstrate Highest Ethical Behavior
- Have Respect for People
- Treat Customers as Kings
- Treat Esprix Assets as if they were Your Own

OUR MISSION: Esprix Technologies is dedicated to the creation of innovative products and services through partnership with our customers thereby enabling us to provide technical development, manufacturing and distribution of performance materials solutions.

OUR VISION: To be the global market leader in the sale, development and application of performance products, fine chemicals and technical services to improve people’s quality of life by “touching lives everyday”.

... founded 2000, Sarasota, FL

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Esprix Distribution & Warehouses
Light-weighting in Automotive

- Light-weighting trend in Automotive has existed for decades
  - Fuel efficiency
  - Environmental benefit
- Different LW Packages will emerge
  - Conventional
    - HS Steel
  - Moderate
    - More LW materials
    - Al, Mg, CF Composites
  - Extreme
    - High CF Composites share
- Overall, LW share will grow from 29% to 67% by 2030

What is Aliphatic Polyketone?

Esprix has its own line of aliphatic Polyketone polymers and compounds called Ketoprix™

Aliphatic Polyketones (PK) are linear, perfectly alternating terpolymers of α-olefins, such as ethylene and propylene and CO.

\[-(CH_2CH_2C)_x-(CH_2CHC)_y-\]

EPCO terpolymers are semi-crystalline engineering resins which play in the upper end of mid-range ETPs or in the lower end of the upper-range ETPs.
Hyosung – Resin Manufacturer

- New PK plant, Ulsan, Korea
- 50 kta expandable to 100 kta
- PK neat resin pellets, powder products
- Special grades available
- Esprix provides Application Development, Marketing, Sales, Compounding, Warehousing & Distribution, Technical Support in North America
# PK vs. Other ETPs – Mechanical

<table>
<thead>
<tr>
<th>Items</th>
<th>Unit</th>
<th>POK</th>
<th>PA6</th>
<th>PA66</th>
<th>PBT</th>
<th>POM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>g/cm³</td>
<td>1.24</td>
<td>1.14</td>
<td>1.14</td>
<td>1.30</td>
<td>1.41</td>
</tr>
<tr>
<td>Melting Temperature</td>
<td>°C</td>
<td>220</td>
<td>220</td>
<td>260</td>
<td>220</td>
<td>160</td>
</tr>
<tr>
<td>Impact Strength</td>
<td>KJ/m²</td>
<td>12</td>
<td>5.2</td>
<td>4.1</td>
<td>5.0</td>
<td>6.5</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>MPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry</td>
<td></td>
<td>70</td>
<td>80</td>
<td>80</td>
<td>55</td>
<td>65</td>
</tr>
<tr>
<td>Conditioned Wet</td>
<td></td>
<td>70</td>
<td>55</td>
<td>70</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wet</td>
<td></td>
<td>60</td>
<td>35</td>
<td>50</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry</td>
<td></td>
<td>270</td>
<td>17</td>
<td>19</td>
<td>16</td>
<td>35</td>
</tr>
<tr>
<td>Conditioned Wet</td>
<td></td>
<td>270</td>
<td>40</td>
<td>60</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wet</td>
<td></td>
<td>390</td>
<td>360</td>
<td>370</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Flexural Modulus</td>
<td>MPa</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dry</td>
<td></td>
<td>1,800</td>
<td>2,600</td>
<td>2,900</td>
<td>2,400</td>
<td>2,500</td>
</tr>
<tr>
<td>Conditioned Wet</td>
<td></td>
<td>1,800</td>
<td>1,200</td>
<td>2,200</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Wet</td>
<td></td>
<td>1,450</td>
<td>600</td>
<td>1,100</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* Dry: 23°C, 50% RH, 24hrs  Conditioned: 23°C, 50% RH, 60days  Wet: 23°C, 90% RH, 60days
** POK : Hyosung M330A properties.
# Glass Fiber Reinforced Ketoprix

## Glass Content, %w

<table>
<thead>
<tr>
<th></th>
<th>20</th>
<th>30</th>
<th>33</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Density (g/cm³)</td>
<td>ASTM D792</td>
<td>1.35</td>
<td>1.47</td>
<td>1.49</td>
</tr>
<tr>
<td>Mold Shrinkage (Flow Direction, %)</td>
<td>ASTM D955</td>
<td>0.3</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Thermal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melting Temp, (°C)</td>
<td>ASTM D1525</td>
<td>220</td>
<td>220</td>
<td>220</td>
</tr>
<tr>
<td>Viscosity, (Pa-s, 280°C)</td>
<td>100-300</td>
<td>100-300</td>
<td>250-350</td>
<td>300-400</td>
</tr>
<tr>
<td>Deflection Temp</td>
<td>ASTM D648</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDT 0.45MPa (°C)</td>
<td></td>
<td>205</td>
<td>205</td>
<td>210</td>
</tr>
<tr>
<td>HDT 1.82MPa (°C)</td>
<td></td>
<td>205</td>
<td>205</td>
<td>210</td>
</tr>
<tr>
<td><strong>Mechanical</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile Strength, 23°C (MPa)</td>
<td>ASTM D638</td>
<td>120</td>
<td>155</td>
<td>160</td>
</tr>
<tr>
<td>Nominal Strain at Break, (%)</td>
<td>ASTM D638</td>
<td>2-4</td>
<td>2-4</td>
<td>2-4</td>
</tr>
<tr>
<td>Tensile Modulus, 23°C (GPa)</td>
<td>ASTM D638</td>
<td>7</td>
<td>10</td>
<td>10.5</td>
</tr>
<tr>
<td>Flexural Strength, 23°C (MPa)</td>
<td>ASTM D790</td>
<td>150</td>
<td>240</td>
<td>240</td>
</tr>
<tr>
<td>Flexural Modulus 23°C (GPa)</td>
<td>ASTM D790</td>
<td>6</td>
<td>8</td>
<td>8.5</td>
</tr>
<tr>
<td>Impact Strength 23°C (kJ/m²)*</td>
<td>ISO 179</td>
<td>13.5</td>
<td>14.8</td>
<td>12.6</td>
</tr>
</tbody>
</table>
PK Benefits and Value Proposition

**Industrial**
- Excellent Chemical Resistance
- High Service Temperature
- Good Toughness
- Low Moisture Sensitivity

**Auto**
- Excellent Chemical Resistance
- Elevated Service Temperature
- Low Moisture Sensitivity
- Lower Density (than steel)
- Light Weight Composites

**E&E / CAM**
- Good Tribology (low friction)
- Good Toughness
- High Strength
- Low Dielectric
- Low Moisture Sensitivity

**Fibers**
- Toughness
- High Strength
- High Yield Elongation
- Low Moisture Sensitivity

**Cpds & Distrib**
- Processable
- Colorable
- Moldable
- Flame Retardant
- Fillers
- Fiber Reinforced
- Low Moisture Sensitivity

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PK Applications

Industrial
- Oil & Gas
  - Pipeliners
- Retail
- Forecourt
- CPI
  - Valves
  - Pumps
- Plumbing
- Conveying
- Agricultural

Auto
- Fuel Tank
- Fuel Lines
- UTH Connectors
- Structural – Composites replace metal

E&E / CAM
- Gears
- Wear Plates
- Bearings
- Bushings
- Dielectric Hardware
- Molded parts

Fibers
- Monofilament
- Multifilament
- Tires
- Textiles

Compounds and Distribution
- Fiber Reinforced
  - Glass
  - Carbon
- Flame Retardant
- Conductive
- Lubricated
- Colors
- Profiles

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Ketoprix Compounds & Grades

**Natural**
- Ultra High MF IM
- High MF IM
- Low MF IM/X
- Low MF X
- All available with additional thermal stabilizers, colors

**Fiber Reinforced**
- Chopped Glass Fiber
  - Natural
  - Black
- Chopped Carbon Fiber
- Aramid Fiber
- Carbon Nano-Structures

**Conductive**
- Thermally conductive
- Electrically conductive

**Flame Retardant**
- UL 94 V0
- UL 94 V1

**Compounds and Distribution**
- Stock Shapes
- Sheets
- Plaques
- Colors (Pantone)
- Filled Compounds

Technical information available on our website landing page:
http://www.esprixtech.com/landing-page/engineering-polymers/

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Ketoprix PK - Easy Processability

- Pre-drying generally not needed prior to molding
- Easy mold filling (low melt viscosity)
- Low clamp tonnage requirements
- Lower density compared to PBT, POM, PPS & PVDF
- Same mold shrinkage rates as PA and POM → no retooling needed
- Shorter molding cycles & high mold definition vs. competitive resins
- No conditioning or annealing required after molding
- Properly molded parts are ductile and can be assembled right after molding
- Isotropic shrinkage in flow and transverse directions → Parts free of warpage
- Good surface adhesion in over-molding with thermoplastic urethanes and thermoplastic elastomers (Santoprene)
PK Dimensional Stability

PK undergoes 3-5X less dimensional change than Polyamide, and is comparable to Polyacetal


<table>
<thead>
<tr>
<th>Polymer</th>
<th>Equilibrium Water Uptake @50% RH (% by Wt)</th>
<th>Dimensional Changes (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PK</td>
<td>.30</td>
<td>.05 - .15</td>
</tr>
<tr>
<td>PA</td>
<td>2.5</td>
<td>.70 - .80</td>
</tr>
<tr>
<td>POM</td>
<td>.20</td>
<td>.10 - .20</td>
</tr>
</tbody>
</table>
Ketoprix™ polyketone resins exhibit excellent resistance to a broad range of chemicals including:

- Aromatic & Aliphatic Hydrocarbons
- Ketones, Esters & Ethers
- Inorganic Salt Solutions
- Weak Acids & Bases
- There are in fact few known solvents for Ketoprix™ PK resins.

The resin structure also confers excellent permeation resistance to aliphatic and aromatic hydrocarbons.

Good utility in automotive fuel tanks, fuel lines, fuel filler necks and under-the-hood components.
Ketoprix PK - Hydrolysis Resistance

Tensile Strength at Yield at 23°C after 25-day exposure to various aqueous environments:

<table>
<thead>
<tr>
<th>Chemical</th>
<th>POLYKETONE M630A MPa</th>
<th>Polyamide 66 MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control (50% Rh)</td>
<td>60.0</td>
<td>57.2</td>
</tr>
<tr>
<td>Water</td>
<td>59.2</td>
<td>33.1</td>
</tr>
<tr>
<td>Seawater</td>
<td>60.0</td>
<td>33.1</td>
</tr>
<tr>
<td>5% w/w Acetic Acid</td>
<td>54.9</td>
<td>33.8</td>
</tr>
<tr>
<td>5% w/w Calcium Chloride</td>
<td>60.0</td>
<td>33.8</td>
</tr>
<tr>
<td>50/50 Antifreeze</td>
<td>59.2</td>
<td>35.8</td>
</tr>
</tbody>
</table>

Tensile testing to ASTM D638 was conducted at 23°C

*With its C-C backbone, PK has excellent hydrolytic & chemical resistance*
Hydrocarbon Resistance of PK

Excellent property retention after exposure to hydrocarbon fuels

Exposure: 4 months in Multicomponent Hydrocarbon Liquid:
Benzene 1%; Toluene 7%; Xylene 11%; Cyclopentenes 6%; Cyclohexanes 6%; C4-C5 17%; C6-C10 42%; C11 10%

Data provided by Shell Canada, 1999
Fuel Permeation Resistance

Lower Fuel Permeation
PK vs. PA-12

- GM 9061-P Permeability Test protocol
- Gravimetric analysis of sealed polymeric tubing
- Electrically conductive PK compounds
  => extrusion of fuel tubing lines
- KPI’s:
  • Excellent Chemical Resistance to Hydraulic Fluids, Antifreeze, Road Salt, Aqueous Solutions
  • Greater Impact Strength
  • Anti-stat / electrically conductive extrusion grades

---

Data from Shell Chemical, 1996
PK Permeability - Theory

Based on gravimetric analysis from PK tube according to Spec GM-9061P

\[
\frac{\partial C}{\partial t} = \frac{1}{r} \frac{\partial}{\partial r} \left( r D \frac{\partial C}{\partial r} \right)
\]

Constitutive Equation for Conservation of Mass, Cylindrical Geometry

**Boundary & Initial Conditions**

BC1: At \( r = a \) (inner radius), \( C = C_1 = Sp^* \) where \( P = D*S \)

BC2: At \( r = b \) (outer radius), \( C = C_2 \rightarrow C_\infty \approx 0 \)

IC: At \( t = 0, a < r < b, C(r,0) = 0 \)

Solving the PDE for the concentration profile:

\[
C(r,t) = \frac{p^*P \ln(b/r)}{D \ln(b/a)} + \pi \sum_{n=0}^{\infty} \frac{p^*P}{D} \frac{J_0(b\lambda_n) J_0(a\lambda_n)}{J_0^2(a\lambda_n) - J_0^2(b\lambda_n)} U_0(r\lambda_n) \exp[-D\lambda_n^2t]
\]

For \( t >> 0 \), integrating Fick’s law equation at outer surface gives the mass lost over time,

\[
M(t) = -2\pi LD \int_0^t r \frac{\partial C}{\partial r} \bigg|_{r=b} dt = \frac{2\pi L p^*P}{\ln(b/a)} t
\]

Plotting mass lost as a function of time gives the Permeability, \( P \) as the slope…

Note: \( U_0(r\lambda_n) = J_0(r\lambda_n)Y_0(b\lambda_n) - J_0(b\lambda_n)Y_0(r\lambda_n) \); \( L=\)tube length; \( p^*=\)vapor pressure; \( D=\)diffusivity; \( S=\)solubility constant; \( C=\)solute concentration
Fuel Permeability Results

UL Gasoline 23C

Linear regression of the slopes of weight loss curves at steady-state vs. time gives the Permeability, $P$, of fuel through the polymer tubing.

See UL Gasoline, 23C as example.

<table>
<thead>
<tr>
<th>Type of Fuel</th>
<th>Temperature, °C (°F)</th>
<th>Permeability, $P$ (cm/s) ($\times 10^{-6}$)</th>
<th>Steady-state Loss, g/(m²-day)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$PK$</td>
<td>$PA12$</td>
</tr>
<tr>
<td>UL Gasoline</td>
<td>23 (73)</td>
<td>$\approx 0$</td>
<td>3,171</td>
</tr>
<tr>
<td>UL Gasoline</td>
<td>93 (200)</td>
<td>328</td>
<td>86,152</td>
</tr>
<tr>
<td>E10</td>
<td>23 (73)</td>
<td>47</td>
<td>2,281</td>
</tr>
<tr>
<td>E10</td>
<td>93 (200)</td>
<td>1,084</td>
<td>6,504</td>
</tr>
</tbody>
</table>
**CO₂, CH₄ Gas Permeability**

**CO₂ Permeability:**
- **PK, PA11, HDPE**
- DAM;

Black outline data point: 50%RH

Data from Shell Canada, 1998

**PK has much better gas barrier resistance than PA11, HDPE**

**CH₄ Permeability:**
- **PK, PA11**
- DAM;

- PK
  - PA11 (Rilsan BESNO P40TL)
  - HDPE
  - Linear (PK)
  - Power (PA11 (Rilsan BESNO P40TL))
  - Power (HDPE)
Electrical Conductivity

Compounded PK with conductive carbon black for ESD applications in extruded Automotive Fuel Lines and IM Fuel Components.

Percolation Curve:
Conductive Carbon Black in PK

Resistivity measurements courtesy of Imerys K&D
Thermal Conductivity

TC Loading Curves: GF and Neat PK with CG

40%w GF PK with Conductive Graphite

Conductivity measurements courtesy of Imerys R&D; Compression molded samples

PK can be compounded with fibers and additives for improved strength and thermal conductivity
## Nanostructures

### Carbon Nanotube modified Polyketone

<table>
<thead>
<tr>
<th>Material</th>
<th>Yield Strength (MPa)</th>
<th>Flexural Strength (MPa)</th>
<th>Flexural Modulus (GPa)</th>
<th>Volume Resistivity (Ω-cm)</th>
<th>Thermal Conductivity (W/m-K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PK</td>
<td>60</td>
<td>68</td>
<td>1.6</td>
<td>$10^{15}$</td>
<td>0.22</td>
</tr>
<tr>
<td>PK + 1% CNT</td>
<td>82</td>
<td>108</td>
<td>3.3</td>
<td>20</td>
<td>0.4</td>
</tr>
<tr>
<td>PK + 2.5% CNT</td>
<td>100</td>
<td>128</td>
<td>4.6</td>
<td>2</td>
<td>0.5</td>
</tr>
</tbody>
</table>

1% CNT / PK  

2.5% CNT / PK

SEM micrographs courtesy of Applied Nanostructured Solutions, LLC
Other PK Automotive Applications

UTH Radiator Tank End Cap

- Current Material: PA66/PA612, 33%GF, K
- Incumbent Performance Issues: Warpage, Hydrolysis, Susceptibility to CaCl₂ exposure
- KPI’s of PK:
  - Chemical Resistance to Antifreeze, Road Salt, Aqueous solutions
  - Impact Strength
  - IM Processability
- Value Proposition:
  - Superior Chemical Resistance
  - Less Warpage, Faster Mold Cycle Time
  - Better long-term mechanical properties
  - Lower Total Cost
Other PK Automotive Applications

**Connector Junction Box**
- Current Material: mPPO
- KPI’s:
  - Dimensional Stability
  - Thin Wall IM Processability
- Value Proposition:
  - Economics
  - Able to mold thin-walled parts
  - Shorter Cycle Time

**Fuel Lines**
- Current Material: PA11/12
- KPI’s:
  - Greater fuel resistance
  - Good impact resistance
  - Electrical Conductivity
- Value Proposition:
  - Better Impact Strength
  - Lower fuel permeation
  - Higher Strength, down-gauging wall thickness

**Bumper Bracket**
- Current Material: PA66
- KPI’s:
  - Impact Strength
  - Dimensional Stability
- Value Proposition:
  - Better Impact Strength
  - Higher Strength, down-gauging wall thickness
  - Less moisture sensitivity
Polyketone is a new engineering resin now commercially available with the following benefits:

- Melt processability in extrusion, injection and blow molding
- High strength, toughness / impact strength, resilience
- Better dimensional & hydrolytic stability than polyamides
- Excellent chemical resistance
- Low permeation rates to hydrocarbon fuels
- Can be compounded with fibers for added strength ...
- And/or with improved electrical and thermal conductivity for use as metal replacements
- Excellent matrix for specialty nanostructure additives to build strength, chemical resistance and stiffness into Auto parts
Ketoprix Team

Cary Veith – President & CEO

Dang Le – Product Manager
June 2016

Tim Morefield – TS Consultant
July 2016

Bob Pilotti – Sales Consultant
August 2016
Thank You

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cveith@esprixtech.com
www.esprixtech.com
## Ketoprix PK vs PA & POM

### Tensile Elongation @ Yield, 23C

<table>
<thead>
<tr>
<th>Resin</th>
<th>POM</th>
<th>PA66, dry</th>
<th>GF PPS</th>
<th>PVDF</th>
<th>Ketoprix™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Elongation @ yield, 23C,%</td>
<td>10</td>
<td>4.5</td>
<td>1.2</td>
<td>7</td>
<td>~25</td>
</tr>
</tbody>
</table>

### Tensile Elongation @ Break, 23C

<table>
<thead>
<tr>
<th>Resin</th>
<th>POM</th>
<th>PA66, dry</th>
<th>GF PPS</th>
<th>PVDF</th>
<th>Ketoprix™</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Elongation @ break, 23C,%</td>
<td>45</td>
<td>25</td>
<td>1.2</td>
<td>35</td>
<td>&gt;350</td>
</tr>
</tbody>
</table>

*Unlike nylon & acetal, PK offers unique combination of strength and resilience*

### Notched Izod Impact at 23C & -40C

<table>
<thead>
<tr>
<th>Resin</th>
<th>POM</th>
<th>PA66, dry</th>
<th>GF PPS</th>
<th>PVDF</th>
<th>Ketoprix™ EK63</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notched Izod Impact, J/m, 23C</td>
<td>64</td>
<td>53</td>
<td>91</td>
<td>160</td>
<td>240</td>
</tr>
<tr>
<td>Notched Izod Impact, j/m, -40C</td>
<td>43</td>
<td>27</td>
<td>N/A</td>
<td>N/A</td>
<td>50</td>
</tr>
</tbody>
</table>

*PK has higher impact resistance than nylon and acetal at both 23C and -40C*
## Ketoprix PK 33GF vs. PA 33GF

<table>
<thead>
<tr>
<th>Properties</th>
<th>Standard</th>
<th>PK/33%GF</th>
<th>PA66 / 33%GF*</th>
<th>PA 610/33% GF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density (g/cm³)</td>
<td>ASTMD792</td>
<td>1.49</td>
<td>1.37</td>
<td>1.37</td>
</tr>
<tr>
<td>Glass Content, %w</td>
<td>ASTM D5630</td>
<td>33</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Equilibrium Water Content, 24 hr, %</td>
<td>ASTM D570</td>
<td>0.30</td>
<td>-</td>
<td>1.9</td>
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<tr>
<td>HDT, 1.8MPa, °C</td>
<td>ASTM D648</td>
<td>218</td>
<td>250</td>
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<tr>
<td>Tensile Strength, MPa, 23°C</td>
<td>ASTM D638</td>
<td>167</td>
<td>190</td>
<td>140</td>
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<tr>
<td>Strain at Break, %</td>
<td>ASTM D638</td>
<td>3</td>
<td>3</td>
<td>5</td>
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<tr>
<td>Tensile Modulus, GPa, 23°C</td>
<td>ASTM D638</td>
<td>11</td>
<td>10</td>
<td>7.2</td>
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<tr>
<td>Flexural Strength, MPa, 23°C</td>
<td>ASTM D790</td>
<td>240</td>
<td>270</td>
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<td>Flexural Modulus, GPa, 23°C</td>
<td>ASTM D790</td>
<td>9</td>
<td>9.6</td>
<td>4</td>
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<tr>
<td>Charpy Impact, kJ/m²</td>
<td>ISO 179</td>
<td>14</td>
<td>12</td>
<td>14</td>
</tr>
</tbody>
</table>

* PA66/33%GF and PA610/33%GF product data from internet sources

itb Auto March 2017
Wear tests run against steel thrust washers in pure sliding contact show that PK has better wear resistance than nylon & acetal.
Creep Resistance Neat PK

- PK has excellent Creep-Rupture resistance
- Superior creep resistance vs. POM, PA66