What’s new in functional fillers?
NEW

CHEAPER

BETTER

SAFER
What's in it for me?

- Lightweighting
- Better Reinforcement
- Quartz “Free”
- Microwave Heating
- Higher Impact
- Radar Blocking
- High Density
- Thermal Conductivity
- Toll Milling
- Preventing Wear
- Sub-micron
- Wollastonite Replacement
- Ultra-low Moisture
- Renewable Content
- Radiation Shielding
Innumerable different reasons to use fillers

- Raise heat resistance
- Increase stiffness
- Increase strength
- Reduce shrinkage
- Improve dimensional stability
- Reduce flammability
- Modify flow
- Increase lubricity
- Decrease permeability
- Increase degradability
- Improve processability
- Reduce creep

- Change electrical properties
- Modify specific gravity
- Improve abrasion resistance
- Improve impact resistance
- Improve thermal conductivity
- Improve moisture resistance
- Increase adhesion
- Appearance, opacity, gloss
- Better scratch resistance
- Magnetic properties
- Thermal property tuning
- Radiation blocking
## World markets by filler (all polymers)

### Huge volumes by value and tonnage

<table>
<thead>
<tr>
<th>Filler Type</th>
<th>2017 Volume (tonnes)</th>
<th>Value (Million USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon black</td>
<td>18,000,000</td>
<td>18,000</td>
</tr>
<tr>
<td>Precipitated silica</td>
<td>1,400,000</td>
<td>1,400</td>
</tr>
<tr>
<td>Fumed silica</td>
<td>110,000</td>
<td>600</td>
</tr>
<tr>
<td>Crystalline silica</td>
<td>300,000</td>
<td>&lt;200</td>
</tr>
<tr>
<td>Precipitated calcium carbonate</td>
<td>275,000</td>
<td>165</td>
</tr>
<tr>
<td>Ground calcium carbonate</td>
<td>12,000,000</td>
<td>2,500</td>
</tr>
<tr>
<td>Talc</td>
<td>1,000,000</td>
<td>600</td>
</tr>
<tr>
<td>Kaolin</td>
<td>1,750,000</td>
<td>800</td>
</tr>
<tr>
<td>Calcined kaolin</td>
<td>175,000</td>
<td>&lt;200</td>
</tr>
<tr>
<td>Wollastonite</td>
<td>150,000</td>
<td>&lt;200</td>
</tr>
<tr>
<td>Barium sulfate</td>
<td>350,000</td>
<td>250</td>
</tr>
<tr>
<td>Natural fibers</td>
<td>350,000</td>
<td>NA</td>
</tr>
<tr>
<td>Others</td>
<td>250,000</td>
<td>NA</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>30,885,000</strong></td>
<td><strong>&gt;2,750</strong></td>
</tr>
</tbody>
</table>

Courtesy of Rothon Consultants 2017
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Hematite

Fe$_2$O$_3$ iron oxide

- Mohs Hardness 5.5-6
- Thermal conductivity high 12.5 W/m.K
- High volumetric specific heat capacity
- Electrical semi-conductor
- Density high 5.2 gcm$^{-3}$
- X-ray blocking
- Sound damping
- Radar absorbing
- Microwave heating
DenzFlex™

Reinforced easy to machine PEEK

Better mechanicals and allows machining of fine features or drilling minute holes
Magnetite

Fe$_3$O$_4$ iron oxide

- Mohs Hardness 5.5-6
- Thermal conductivity high 5.1 W/m.K
- High volumetric specific heat capacity
- Electrical semi-conductor
- Density high 5.2 gcm$^{-3}$
- X-ray blocking
- Sound damping
- Radar absorbing
- Microwave heating
Magnetic
## Properties of magnetite

*In contrast to common fillers*

<table>
<thead>
<tr>
<th>Property</th>
<th>Typical Mineral Filler</th>
<th>Magnetite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>White</td>
<td>Black</td>
</tr>
<tr>
<td>Density</td>
<td>2.5-3.0 g cm⁻³</td>
<td>5.2 g cm⁻³</td>
</tr>
<tr>
<td>Mohs Hardness</td>
<td>2-3</td>
<td>5.5-6</td>
</tr>
<tr>
<td>Attraction to a Magnet</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>Insulator</td>
<td>Conductive</td>
</tr>
<tr>
<td>Chemical composition</td>
<td>Carbonates &amp; silicates</td>
<td>Oxide</td>
</tr>
<tr>
<td>Volumetric heat capacity</td>
<td>2.1 kJ L⁻¹ K⁻¹</td>
<td>3.8 kJ L⁻¹ K⁻¹</td>
</tr>
<tr>
<td>Microwave heatable</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Radiation blocking</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>
### Properties of FiberFlex™

*Amorphous mineral fiber - similar properties to treated wollastonite*

<table>
<thead>
<tr>
<th>Property</th>
<th>Virgin PP</th>
<th>FiberFlex™ 10%</th>
<th>Wollastonite 10%</th>
<th>FiberFlex™ 30%</th>
<th>Wollastonite 30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>MFI (g/10min)</td>
<td>12.6</td>
<td>13.4</td>
<td>12.7</td>
<td>12.3</td>
<td>14.3</td>
</tr>
<tr>
<td>Density (g/cc)</td>
<td>0.90</td>
<td>0.964</td>
<td>0.963</td>
<td>1.127</td>
<td>1.134</td>
</tr>
<tr>
<td>Flexural secant modulus (psi)</td>
<td>131700</td>
<td>150800</td>
<td>148800</td>
<td>198200</td>
<td>210000</td>
</tr>
<tr>
<td>Flexural tangent modulus (psi)</td>
<td>144000</td>
<td>182000</td>
<td>185000</td>
<td>300500</td>
<td>318000</td>
</tr>
<tr>
<td>Flexural maximum strength (psi)</td>
<td>4140</td>
<td>4430</td>
<td>4440</td>
<td>4800</td>
<td>5100</td>
</tr>
<tr>
<td>Notched Izod RT (ft-lb/in)</td>
<td>1.2</td>
<td>0.75</td>
<td>0.75</td>
<td>0.61</td>
<td>0.75</td>
</tr>
</tbody>
</table>

FiberFlex™ is an experimental grade without surface treatment – wollastonite is a commercial, silane treated type.
Oolitic Aragonite – renewable filler

Finally, a renewable filler that makes sense

Aragonite

CaCO$_3$ calcium carbonate

- Mohs Hardness 3.5-4
- Density 2.84 gcm$^{-3}$
- Needle-shaped crystals
- Newly deposited
- Deposited 10x faster than harvesting
- Therefore renewable material

Gives white calcium carbonate when milled to filler-sized particles (Hunter L value ~91)
**Toll milling**

- 1-2MT trial run
- Match target PSD
- Qualify a sample
- Price quote
- Define COA
- Packaging options
- Warehousing & delivery
- Surface treatment options
- Sub-micron possible
- Low-moisture capability
- Huge mills = lower prices
- Mica, ATH, MDH, glass...

### Services

**Milling technologies & services**

- Milling capabilities using cutting edge equipment & processes
- Sub-micron & high aspect ratio capability
- In-line surface treatment optional
- Custom sieving
- In-house QC on every batch
- Two sites for security of supply
- USA warehousing network

### About Us

**Key points**

- ISO 9001 certified
- Decades of experience
- Large capacity
- Family owned

### Testimonials

- "We were blown away by the packaging"
- "Fast turn around"
- "Great value"

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Surface treatment types

Dispersants improve impact resistance & coupling agents for strength
Phlogopite mica outperforms the best talc

Mica for better reinforcement & lightweighting

<table>
<thead>
<tr>
<th>Particle Dimensions (microns)</th>
<th>Wollastonite</th>
<th>Talc</th>
<th>HAR Talc</th>
<th>Mica</th>
</tr>
</thead>
<tbody>
<tr>
<td>(D_{50})</td>
<td>3.5</td>
<td>12</td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>(D_{90})</td>
<td>13</td>
<td>40</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>Aspect Ratio</td>
<td>10:1</td>
<td>20:1</td>
<td>40:1</td>
<td>100:1</td>
</tr>
</tbody>
</table>

- Aspect ratio determines stiffness, strength, HDT, barrier and CLTE
- Phlogopite mica can achieve much higher aspect ratio than talc
- Less phlogopite is needed to achieve equivalent mechanicals
# Phlogopite mica outperforms every mineral (in PA 6,6)

<table>
<thead>
<tr>
<th>Property</th>
<th>Mica 40%</th>
<th>CaCO₃ 40%</th>
<th>Wollastonite 40%</th>
<th>Glass Beads 40%</th>
<th>Clay 40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural Modulus (GPa)</td>
<td>10.6</td>
<td>4.55</td>
<td>5.45</td>
<td>4.24</td>
<td>6.96</td>
</tr>
<tr>
<td>Flexural Strength (MPa)</td>
<td>179</td>
<td>114</td>
<td>53.1</td>
<td>109</td>
<td>163</td>
</tr>
<tr>
<td>Ultimate Tensile Stress (MPa)</td>
<td>105</td>
<td>72.4</td>
<td>33.1</td>
<td>67.6</td>
<td>75.2</td>
</tr>
<tr>
<td>Break Strain (%)</td>
<td>140</td>
<td>144</td>
<td>144</td>
<td>165</td>
<td>195</td>
</tr>
<tr>
<td>Break Strain (%)</td>
<td>2.7</td>
<td>2.9</td>
<td>3.0</td>
<td>3.2</td>
<td>2.5</td>
</tr>
<tr>
<td>Unnotched Charpy (Jm⁻¹)</td>
<td>433</td>
<td>513</td>
<td>502</td>
<td>294</td>
<td>657</td>
</tr>
<tr>
<td>Notched Charpy (Jm⁻¹)</td>
<td>30</td>
<td>25</td>
<td>30</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>Shrinkage (%)</td>
<td>0.3</td>
<td>1.2</td>
<td>0.9</td>
<td>1.1</td>
<td>0.4</td>
</tr>
<tr>
<td>HDT @ 1.82 MPa (°C)</td>
<td>238</td>
<td>198</td>
<td>221</td>
<td>208</td>
<td>199</td>
</tr>
<tr>
<td>Thermal Expansion (10⁻⁵/°C)</td>
<td>1.2</td>
<td>1.5</td>
<td>1.4</td>
<td>1.5</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Phlogopite mica outperforms every mineral with glass fiber (in PA 6)

<table>
<thead>
<tr>
<th>Property</th>
<th>GF 25% Talc 15%</th>
<th>GF 25% Clay 15%</th>
<th>GF 25% Wollastonite 15%</th>
<th>GF 25% Phlogopite Mica 15%</th>
<th>GF 40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural Modulus (MPa)</td>
<td>9843</td>
<td>9350</td>
<td>9080</td>
<td>10550</td>
<td>11980</td>
</tr>
<tr>
<td>Flexural Strength (MPa)</td>
<td>210</td>
<td>213</td>
<td>226</td>
<td>231</td>
<td>290</td>
</tr>
<tr>
<td>Tensile Modulus (MPa)</td>
<td>11400</td>
<td>9950</td>
<td>10100</td>
<td>12200</td>
<td>13215</td>
</tr>
<tr>
<td>Break Stress (MPa)</td>
<td>140</td>
<td>144</td>
<td>144</td>
<td>165</td>
<td>195</td>
</tr>
<tr>
<td>Break Strain (%)</td>
<td>2.4</td>
<td>3.4</td>
<td>2.6</td>
<td>2.4</td>
<td>2.6</td>
</tr>
<tr>
<td>Unnotched Charpy (kJm²)</td>
<td>52.3</td>
<td>43.6</td>
<td>50.3</td>
<td>60</td>
<td>79</td>
</tr>
<tr>
<td>Notched Charpy (kJm²)</td>
<td>7.4</td>
<td>5.6</td>
<td>6.9</td>
<td>8.6</td>
<td>12.8</td>
</tr>
<tr>
<td>Shrinkage (%)</td>
<td>0.22</td>
<td>0.26</td>
<td>0.23</td>
<td>0.22</td>
<td>0.1</td>
</tr>
<tr>
<td>Shrinkage</td>
<td></td>
<td>(%)</td>
<td>0.91</td>
<td>0.99</td>
<td>1.04</td>
</tr>
<tr>
<td>Warpage (%)</td>
<td>0.69</td>
<td>0.73</td>
<td>0.81</td>
<td>0.59</td>
<td>0.88</td>
</tr>
</tbody>
</table>
Higher aspect ratio leads to better performance

- Higher aspect ratio means better stiffness, strength, HDT and barrier with lowest CLTE, shrinkage and warpage
- 12% ThermaFlex™ mica to replace 20% talc with the same properties
- Well proven in PA6, PA6,6 and PP for over 30 years
- ThermaFlex™ - no detectable quartz (safe, non-abrasive)
- Full range of sizes available
- Custom sieved grades for better impact
- Cost-effective silane treatments upon request
Particle size distribution

Particle size & impact resistance

Particle size (% in range)

Particle size (µm)

- Raise viscosity & agglomerate
- Reduce impact resistance
Effect of particle size on dispersibility

A few larger particles ruin impact and elongation

$D_{50} = 0.85$ micron, $D_{98} = 5$ microns
"T - GRADES" are custom sieved to remove the coarser particles.
Filler properties & why quartz matters

Quartz relates to safety but also machine wear & abrasion

- Must be insoluble and inert
- Colour consistency
- Abrasion (Quartz impurities dominate)
- Electrical Properties (Traces of soluble salts)
- Stability (Transition metals can attack polymers - Cu, Fe, etc.)
- Health (Quartz, asbestos)
Quartz “free” mineral range

Calcium Carbonate

Calcined Calcium Sulfate
TiO$_2$ Extender

Talc

Blanc Fixe
Barium Sulfate

FiberFlex™
Wollastonite Replacement

Hollow Glass Spheres

BriteFlex™ Muscovite Mica
(Under Development)

DenzFlex™ Fe$_2$O$_3$
Iron Oxide

Expandable Polymer Spheres

ThermaFlex™
Phlogopite Mica

Quartz “free” means <0.1 weight%, i.e. below the detection limit
Conclusions

Lots new in the world of fillers

- ThermaFlex™ mica for better reinforcement to replace talc and save weight
- DenzFlex™ iron oxide for sound damping and x-ray blocking
- FiberFlex™ amorphous mineral fibers to replace wollastonite
- CalciFlex™ renewable calcium carbonate from the ocean
- Quartz “free” mineral range for better safety and lower machine wear
- Toll milling and mixing of chemicals and minerals
- New continuous silane treatment technology for improved output and far better economics
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Experience

Leading consultant, innovator, speaker, author

- Over 25 years of experience innovating in industry: Cookson, Institute for Surface Chemistry (YKI), Electrolux (Frigidaire), BASF, Hybrid Plastics, Applied Minerals, LKAB Minerals, Phantom Plastics, Kish Company / Arctic Minerals

- Expert in plastics, filled plastics, mineral fillers, specialty chemicals, materials and consultant to the Fortune 500 (P&G, Total, CBS, Apple, HP, Exxon etc.)

- Serial innovator: over 30 registered inventions, 15 patents & 6 Innocentive open innovation awards totaling > $50 000 (top 0.01% of registered innovators)

- Articles (40), book chapters (9), presentations (40), workshops (50)

- Fellow of the Royal Society of Chemistry & Chartered Chemist

- Awards for speaking, Frost & Sullivan Award, R&D 100 Award

- Voted #1 plastics expert world-wide out of over 14 000 peers