EXCITING FUNCTIONAL FILLERS

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OUTLINE

• Introduction to LKAB Minerals (formerly Minelco)
• Magnetite – a multi-functional specialty filler
• Phlogopite MicaFort PW80 a new breakthrough grade
• Performance comparison in nylon and PP
• Conclusions
PRESENTER

- KTH, Ytkemiska Institutet, Electrolux (Frigidaire) Stockholm, Electrolux Italy, BASF Germany, Hybrid Plastics, Phantom Plastics, Applied Minerals, LKAB Minerals

- Born in USA, grew up in the UK, 9 years in Sweden, 1 Italy, 4 Germany and now USA 6 years (American & Swedish citizen)

- Experienced in R&D, Marketing, Product Development, Sales

- Expertise in plastics, specialty minerals, materials

- World-class innovator (5 open innovation challenges, 13 patents)

- >30 articles, 6 book chapters, 3 encyclopedia chapters

- >30 conference presentations with multiple awards
THE LKAB GROUP IN BRIEF

- World leading producer of upgraded iron ore
- Delivered 25.5 Million MT in 2013, plan to grow to 37 Million MT
- Two underground mines in Kiruna and Malmberget and open pit mining in Svappavaara
- Producer of 90% of EU’s iron ore
- ~4,400 employees
- 30 companies in 15 countries
  - E.g. Drilling, Concrete, Explosives, Railway, Harbour, Construction.
- Turnover 2013: USD 3.2 Billion
BROAD APPLICABILITY

We focus our R&D resources on mineral and application development in the areas of:

- Civil Engineering and Construction
- Polymers and Coatings
- Refractory and Foundry
MAGNiF – HIGH PURITY MAGNETITE
MAGNETITE PROCESSING
MAGNETITE ORE

1. Density $5.2 \text{ gcm}^{-3}$
2. Moh Hardness $\sim 6$
3. Semi-conductive
4. Thermally conductive
5. High specific heat capacity
6. Extremely pure

1. Sound deadening, weights
2. Solid surfaces
3. Anti-static, shielding, induction & microwave heatable, tracer
4. Improved productivity
5. Heat storage
6. Food contact approved
DENSITY ENHANCEMENT WITH MAGNIF

\[ \rho_c = \frac{\rho_f \times \rho_p}{\rho_p m_f + \rho_f \times (1-m_f)} \]

- \( \rho_c \): density of the composite
- \( \rho_f \): density of the filler
- \( \rho_p \): density of the polymer
- \( m_f \): weight fraction of filler

Graph showing the relationship between density and weight % filler for Talc in PP, Magnetite in PP, and Tungsten in Nylon.
MAGNETITE IN USE
PHLOGOPITE MICA

1. Chemically inert
2. Electrical insulator
3. Bronze colored
4. Stable to >900°C
5. Platy shape
6. Extremely pure (no quartz*)

1. Barrier
2. Dielectric
3. Pigment
4. FR applications
5. Reinforces in two directions, sound deadening
6. Food contact approved

* No detectable quartz within the limits of XRD (<0.1%)
ASPECT RATIO AND FLEXURAL MODULUS

SEM OF PHLOGOPITE MICAFORT PW80

Mag = 2.00 K X

10μm

EHT = 5.00 kV
WD = 12 mm

Detector = SE2
Photo No. = 685
MINERAL REINFORCEMENTS COMPARED

<table>
<thead>
<tr>
<th>Particle Dimensions (Malvern)</th>
<th>Calcined Clay</th>
<th>Wollastonite</th>
<th>Talc</th>
<th>Phlogopite MicaFort PW80</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_{50}$</td>
<td>3</td>
<td>3.5</td>
<td>12</td>
<td>37</td>
</tr>
<tr>
<td>$D_{90}$</td>
<td>10</td>
<td>13</td>
<td>40</td>
<td>95</td>
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<tr>
<td>Aspect Ratio</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td>Very High</td>
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<tr>
<td>Reinforces in</td>
<td>2 directions</td>
<td>1 direction</td>
<td>2 directions</td>
<td>2 directions</td>
</tr>
</tbody>
</table>

In real parts platy fillers give superior strength and modulus plus low warpage.
# REINFORCEMENT COMPARISON IN PA6

<table>
<thead>
<tr>
<th>Property</th>
<th>Talc 40%</th>
<th>Calcined Clay 40%</th>
<th>Wollastonite 40%</th>
<th>Phlogopite Mica 40%</th>
<th>GF 40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flexural Modulus (MPa)</td>
<td>7400</td>
<td>6120</td>
<td>5514</td>
<td>10370</td>
<td>11980</td>
</tr>
<tr>
<td>Flexural Strength (MPa)</td>
<td>120</td>
<td>150</td>
<td>135</td>
<td>155</td>
<td>290</td>
</tr>
<tr>
<td>Tensile Modulus (MPa)</td>
<td>7470</td>
<td>6313</td>
<td>5450</td>
<td>11160</td>
<td>13215</td>
</tr>
<tr>
<td>Break Stress (MPa)</td>
<td>74</td>
<td>87</td>
<td>83</td>
<td>95</td>
<td>195</td>
</tr>
<tr>
<td>Break Strain (%)</td>
<td>2.8</td>
<td>6.4</td>
<td>8.4</td>
<td>1.7</td>
<td>2.6</td>
</tr>
<tr>
<td>Unnotched Charpy (kJm⁻²)</td>
<td>28.5</td>
<td>80</td>
<td>No Break</td>
<td>29</td>
<td>79</td>
</tr>
<tr>
<td>Notched Charpy (kJm⁻²)</td>
<td>3.5</td>
<td>6.4</td>
<td>6.4</td>
<td>4.0</td>
<td>12.8</td>
</tr>
<tr>
<td>Shrinkage (％)</td>
<td>0.65</td>
<td>1.31</td>
<td>1.06</td>
<td>0.58</td>
<td>0.1</td>
</tr>
<tr>
<td>Shrinkage (║) (％)</td>
<td>0.97</td>
<td>1.66</td>
<td>1.64</td>
<td>0.87</td>
<td>0.98</td>
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<tr>
<td>Warpage (％)</td>
<td>0.32</td>
<td>0.35</td>
<td>0.58</td>
<td>0.29</td>
<td>0.88</td>
</tr>
</tbody>
</table>

LKAB Minerals data from accredited external laboratory
# REINFORCEMENT COMPARISON IN PA6

<table>
<thead>
<tr>
<th>Property</th>
<th>GF25% Talc15%</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>
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<tr>
<td>Flexural Strength (MPa)</td>
<td>210</td>
<td>213</td>
<td>226</td>
<td>231</td>
<td>290</td>
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<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 (kJm⁻²)</td>
<td>52.3</td>
<td>43.6</td>
<td>50.3</td>
<td>60</td>
<td>79</td>
</tr>
<tr>
<td>Notched Charpy (kJm⁻²)</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>
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<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>

LKAB Minerals data from accredited external laboratory
PHLOGOPITE MICAFOORT – IN PP
VHAR MICAFORT VS HAR TALC

LKAB Minerals data from accredited external laboratory – PP Copolymer 65%, Impact Modifier 15%, Mineral 20%, Additives <1%
VHAR MICAFORT VS HAR TALC

LKAB Minerals data from accredited external laboratory – PP Copolymer 65%, Impact Modifier 15%, Mineral 20%, Additives <1%
VHAR MICAFORT VS HAR TALC

Flexural Modulus (MPa)

- 5% PW80 Mica
- 10% PW80 Mica
- 20% PW80 Mica
- 30% PW80 Mica
- 20% 10μm Talc
- 20% 20μm Talc
- 20% 45μm Talc

LKAB Minerals data from accredited external laboratory – PP Copolymer 65%, Impact Modifier 15%, Mineral 20%, Additives <1%
VHAR MICAFORT VS HAR TALC

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VHAR MICAFORT VS HAR TALC

LKAB Minerals data from accredited external laboratory – PP Copolymer 65%, Impact Modifier 15%, Mineral 20%, Additives <1%
VHAR MICAFORT VS HAR TALC

Notched Charpy (kJ.m^-2)

- 5% PW80 Mica
- 10% PW80 Mica
- 20% PW80 Mica
- 30% PW80 Mica
- 20% 10μm Talc
- 20% 20μm Talc
- 20% 45μm Talc

LKAB Minerals data from accredited external laboratory – PP Copolymer 65%, Impact Modifier 15%, Mineral 20%, Additives <1%
VHAR MICAFORT VS HAR TALC

LKAB Minerals data from accredited external laboratory – PP Copolymer 65%, Impact Modifier 15%, Mineral 20%, Additives <1%
LKAB Minerals data from accredited external laboratory – PP Copolymer 65%, Impact Modifier 15%, Mineral 20%, Additives <1%
MICA FOR SOUND DAMPING

VHAR PHLOGOPITE MICAFORT

- Very high purity phlogopite mica as starting material
- State of the art wet grinding and classification for optimal aspect ratio and particle size control
- Excellent reinforcement alone or in combination with glass fiber
- The best solution for nylon, PP and other engineering thermoplastics, comparable to double the amount of talc
- Warpage control, superb electrical properties, scratch resistance and sound damping are other key advantages
CONCLUSIONS

• Specialty minerals allow new levels of performance
• Magnetite has been used for decades but its full potential has not yet been tapped
• Established minerals like mica can still be innovative and are especially suited to automotive applications
• One needs new ingredients to make better compounds
CUSTOMER FEEDBACK

“It’s magic”
President of coatings company

“It blew everything else out of the water”
PhD scientist at leading engineering plastics company

“Significantly better than everything else”
Fortune 100 company

“I’m in awe of what this stuff can do”
PhD scientist at leading aesthetic products company
“A ship is safe in harbor, but that’s not what ships are for.”
― William G.T. Shedd
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