MARTOXID® TM Thermally Conductive Fillers

SUPERIOR THERMAL MANAGEMENT SOLUTIONS FOR POLYMERIC MATERIALS
As electronic components continue to get smaller and deliver more power than ever before, the heat dissipation requirements of the component’s compound must increase. Heat management and proper integrative and miniature design are critical in order to sustain performance and reliability, since high temperatures can render electronic parts inoperable.

There is a trend toward using components produced of polymeric composite materials, because they are lighter and less costly in production than comparable metal parts. However, unmodified polymeric systems are not ideal because they behave as thermal insulators and not as thermal conductors. Polymeric systems require efficient thermally conductive additives to dissipate the heat.

There are numerous applications where thermal management is needed, such as automotive, aerospace, electronics, mechatronics and photonics. Thermal interface materials are employed for functional sheets, IC packaging, heat sinks, electrical power appliances, tapes, pads, thermal gap fillers, encapsulation compounds, adhesives, grease, sealing materials, coatings, SF6 gas circuit breakers, solar panels and so forth. Filled polymers are ideal materials for the design of more efficient, integrative and complex components. At an increasing rate, they are replacing more costly metal components and other materials.

Introducing the MARTOXID® TM Series of Thermally Conductive and Electrically Insulative Fillers

To meet the demanding requirements of a certain polymeric-related application, three series of high-performing MARTOXID® TM alumina-based fillers have been developed:

**Economic: MARTOXID® TM-1000 grades** serve standard applications at reasonable filler degrees performing at a fit and proper thermal conductivity.

**Preferred: MARTOXID® TM-2000 grades** are dedicated to sophisticated applications needing high filler degrees in providing a high thermal conductivity and balanced mechanical and rheological behavior.

**Superior: MARTOXID® TM-3000 grades** are designed for high performance applications to guarantee extreme filling degrees (maximum condition above the percolation threshold) coupled with a reduced viscosity and a significantly improved workability in processing of polymers. MARTOXID® TM-3000 products can be loaded up to 90%. Denser packing of the filler particles ensures an outstanding thermal conductivity and an excellent mechanical strength.
Martinswerk has met the challenge by introducing a series of thermally conductive powders for modified polymeric systems. MARTOXID® TM heat conductive alumina-based fillers are easy-to-use, designed to improve the coexistence between filler and matrix in thermally sensitive environments. They allow the high loadings necessary to transfer heat away from the electronic part, and the resulting part has exceptional properties appropriate for thermal management of polymeric and resin compounds.

The new MARTOXID® TM grades were developed and tailored to provide improved processability and better final product characteristics. In order to achieve high loads, fillers must be compatible/adherent with the polymer matrix, and the final product should possess high mechanical strength. MARTOXID® TM features specific particle shapes, fitted particle size distributions and optimized functional surface characteristics which are designed especially for electronic applications. The improved dispersibility of MARTOXID® TM results in lower viscosities at high filler contents.

Numerous applications also require electrical insulation. On account of its appropriate dielectric properties, in many cases alumina is the filler of choice for electrically insulating polymers. It is of specific interest because of its ability to decrease the coefficient of thermal expansion to limit shrinkage, improve heat distortion temperature, and impart high mechanical strength.

### Typical Properties of Aluminum Oxide (α-Al₂O₃)

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>[g/cm³]</td>
<td>3.98</td>
</tr>
<tr>
<td>Color</td>
<td></td>
<td>White</td>
</tr>
<tr>
<td>Hardness</td>
<td>HV2 [kN/mm²]</td>
<td>18</td>
</tr>
<tr>
<td>Thermal Expansion Coefficient</td>
<td>[x 10⁻⁶/K]</td>
<td>8</td>
</tr>
<tr>
<td>Specific Heat</td>
<td>[J/kgK]</td>
<td>1000</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>[W/mK]</td>
<td>30</td>
</tr>
<tr>
<td>Electrical Resistivity</td>
<td>[Ωcm]</td>
<td>&gt;10¹⁴</td>
</tr>
<tr>
<td>Dielectric Strength</td>
<td>[MV/m]</td>
<td>&gt;13</td>
</tr>
</tbody>
</table>

Alumina has an intrinsic thermal conductivity in the range of 30 W/mK. In contrast to other fillers, surface modified alumina can be filled in polymeric compounds at very high loads due to its improved rheological properties and packing density. This beneficial effect facilitates an intense percolation of the contributing particles, which consequently ends up in a higher utilization rate. Most fillers have poor packing of the particles caused by steric effects, and many are also limited in the integral thermal conductivity due to textural effects transferring the heat in one preferred direction. Alumina provides almost isotropic properties (in-plane and through-plane), and is well suited for integrative, orientation independent designs.

Micronized aluminas, when being dispersed in polymeric compounds, cannot develop the full potential of heat transfer of the crystalline solid body. With the newly developed MARTOXID® TM grades, up to 15% of the heat transfer can be accomplished at high filling degrees (up to 92 wt. %).

### Cost Performance

Due to high loadings (necessary to achieve high thermal conductivity), the filler content contributes significantly to the cost of the formulation. On a volume basis, alumina powders comparable in cost to polymeric materials are much more economical than carbide and nitride powders.

### The Environment

Alumina is a non-hazardous substance which is listed in REACH and other national chemical inventory lists. MARTOXID® TM alumina-based fillers pose little danger to health, safety and the environment.
MARTOXID® TM alumina-based fillers are tailored to produce highly filled compounds. The grain morphology, the grain size distribution and the modification of the particle surface are the key characteristics for improved dispersibility of the filler and the related processability of the compound. All grades are very low in soda content which prevents undesired chemical/rheological interactions.

As a response to the need for diverse and specific requirements, Martinswerk offers the fully deagglomerated MARTOXID® TM grades in both the uncoated and coated forms, which are compatible with the various polymeric systems even at the highest filler contents.

Three Series of MARTOXID® TM Products are Available:

- **Economic**
  - TM-1000

- **Preferred**
  - TM-2000

- **Superior**
  - TM-3000

Depending on the final product design, i.e., thermal conductivity, rheological and mechanical properties, the appropriate grade can be applied.
**MARTOXID® TM Alumina-Based Fillers:**
The Science Behind High Performance

### Economic/Preferred MARTOXID® TM-1000 and TM-2000 Grades

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Content of Al₂O₃</td>
<td>%</td>
<td>&gt;99</td>
<td>&gt;99</td>
<td>&gt;99</td>
</tr>
<tr>
<td>Content of α-Al₂O₃</td>
<td>%</td>
<td>&gt;95</td>
<td>&gt;95</td>
<td>&gt;95</td>
</tr>
<tr>
<td>Specific Surface Area (BET)</td>
<td>m²/g</td>
<td>5,0</td>
<td>1,8</td>
<td>1,2</td>
</tr>
<tr>
<td>Tapped Density</td>
<td>kg/m³</td>
<td>1470/1570</td>
<td>1200/1670</td>
<td>1340/1800</td>
</tr>
<tr>
<td>Surface Treatment (Coating)</td>
<td></td>
<td>Uncoated/Coated</td>
<td>Uncoated/Coated</td>
<td>Uncoated/Coated</td>
</tr>
</tbody>
</table>

**MARTOXID® TM-1000 Grades: Appearance and Grain Morphology (SEM)**

- **TM-1250**
- **TM-1320**
- **TM-1410**

### Superior MARTOXID® TM-3000 Grades: Low Viscosity

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Unit</th>
<th>TM-3220</th>
<th>TM-3310</th>
<th>TM-3510</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content of Al₂O₃</td>
<td>%</td>
<td>&gt;99</td>
<td>&gt;99</td>
<td>&gt;99</td>
</tr>
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<td>Content of α-Al₂O₃</td>
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<tr>
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<td>m²/g</td>
<td>1,8</td>
<td>1,2</td>
<td>0,9</td>
</tr>
<tr>
<td>Tapped Density</td>
<td>kg/m³</td>
<td>1840</td>
<td>2160</td>
<td>2100</td>
</tr>
<tr>
<td>Surface Treatment (Coating)</td>
<td></td>
<td>Tailored Coating</td>
<td>Tailored Coating</td>
<td>Tailored Coating</td>
</tr>
</tbody>
</table>
MARTOXID® TM Flexibility with Polymer and Resin Compounds

MARTOXID® TM alumina-based fillers perform well with numerous and various polymer and resin compounds, such as:

- Synthetic resins like epoxies, acrylics, esters, urethanes, silicones, phenolics, etc.
- Thermoplastics and thermoplastic elastomers like polyethylene, polypropylene, polybutylene, terephthalate, polyamide, polyimide, polystyrene, polycarbonate, PE-copolymer, ethylene-vinyl acetate, polyolefin-styrene, etc.
- Rubbers/elastomers based upon nitrile, butadiene, isobutylene isoprene, styrene butadiene, etc.

Our MARTOXID® TM Alumina-Based Fillers are Versatile, Applicable Products for High-Performing Compounds

**Key Performance Benefits:**

- Thermal conductivity appropriate for thermal management also enabling quick cooling-off phase (through-plane)
- Stability at higher temperature levels and enhanced thermal stability of the final composites
- Optimized particle size distribution allowing miniature design and low bond lines
- Flat and smooth surface improving the inter-contact between thermal interfaces
- Low heat expansion coefficient allowing tight dimensional accuracies
- Excellent electrical insulation and tracking resistance due to high dielectric strength
- Defined pot life of resin compounds due to tailored surface reactivity
- Finely dispersed powder providing sufficient mechanical strength at high loading levels
- Chemically stable and inert material in contact with polymeric matrix prolonging shelf life of compound
- Mechanical wear of production equipment comparable with silica powder and glass fiber

MARTOXID® TM: Effective Cooling Illustrated by Heat Dissipation Testing

Thermal imaging of square-shaped samples with different TC values for the simulation of the heat dissipation of a hot spot: the images show the temperature decay after applying a cylindrical heat source (60°C) for 20 seconds. The heat source was removed (time=0 seconds), and the samples eventually cooled down to room temperature.
The MARTOXID® TM alumina-based filler series are outstanding all-around products with many useful properties. The newly engineered MARTOXID® TM grades are optimized aluminas for highly effective thermal management providing excellent cost performance. MARTOXID® TM is something heat management should never be without.

Viscosity Ranges of MARTOXID® TM Series
(Viscosity vs. Shear Rate)

Reasonably low viscosities at high filler contents can be obtained by optimizing surface treatment of the particles and particle size modality and morphology, which is advantageous for further processing.

Viscosity measurements were conducted in RheoStress® 6000 rotational viscometer, rotor Z25-DIN 53019 in Caradol® polyether polyol, 72 wt. % MARTOXID® TM @ 23°C.

Through-Plane Thermal Conductivity – Example in Engage® Elastomer

A filler content of 50-67% (v/v) is easily realized in polymeric compounds as shown in the data at left. Substantial thermal conductivities can be achieved at high filling degrees, generally on the order of 2.5-3.0 W/mK (through-plane). “In-plane” conductivity values are often higher than “through-plane” values.

Thermal conductivity measurements were carried out using a steady state method via THASYS (THA01-1419) ASTM 1114-06 @ 23°C. Polymer: Engage® 8003 polyolefin elastomer (ethylene-octene copolymer).

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Introducing the...

**Martoxid® TM-4000 Series**

**THERMALLY CONDUCTIVE, ELECTRICALLY INSULATIVE ADDITIVES, BASED ON ADVANCED ALUMINUM OXIDE TECHNOLOGY, ESPECIALLY DESIGNED FOR HEAT DISSIPATION SOLUTIONS FOR POLYAMIDES (E.G., PA-6, PA-6,6)**

**Applications:**
- Aerospace
- Automotive
- LED
- E&E (e.g., Housing, Connectors, Switchgear, Overvoltage Protection)

**Available Martoxid® TM-4000 grades:**
**Martoxid® TM-4250 • Martoxid® TM-4410 • Martoxid® TM-4220**
Key Performance Advantages:
- Orientation independent thermal conductivity; i.e., high through- and in-place values
- Low viscosity and good flowability which are essential for efficient extrusion and injection molding; i.e.,
  - Higher throughput during extrusion
  - Lower pressure needed for injection molding
  - Outstanding energy efficiency
- Tailored particles’ morphology and surface treatment which significantly determine the final compound’s performance; i.e., superior mechanical properties; e.g., elongation at break and charpy impact strength

<table>
<thead>
<tr>
<th>Martoxid® TM-4410 / PA-6</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Loading (Wt. %)</strong></td>
</tr>
<tr>
<td><strong>Loading (Vol. %)</strong></td>
</tr>
<tr>
<td><strong>Thermal Conductivity (W/mK)</strong></td>
</tr>
<tr>
<td><strong>Elongation @ Break (%)</strong></td>
</tr>
<tr>
<td><strong>E-Modulus (MPa)</strong></td>
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<tr>
<td><strong>Tensile Strength (MPa)</strong></td>
</tr>
<tr>
<td><strong>Charpy Impact Strength (kJ/m²)</strong></td>
</tr>
</tbody>
</table>

* @ 15 J
** @ 7,5 J

Huber | Martinswerk Unsurpassed Customer Service and Care
Huber | Martinswerk has over a century of experience producing high-performing alumina-based specialties for use in a wide variety of applications including engineering plastic, rubber compounds and composites. We look forward to meeting your requirements for high-quality specialty products backed by superior technical service. If you require more specific information, please contact us:

Email: thermal.management@martinswerk.com
Call: Dr. Henning Hofius, Manager of Business Development and Key Accounts - Specialty Products: +49/(0)2271902234
Dr. Bashar Diar Bakerly, Senior Research & Development Specialist: +49/(0)2271902399
Web: www.hubermaterials.com