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Optimized Thermomanagement with mineral filled plastics

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Abstract

The automotive industry is since ever a pulser and a driver for new material developments and the future electrical cars are for sure an excellent area, especially for new and smart plastic materials.

In electromobility objectives of future applications and the associated requirements are closely linked to the use of new and innovative plastic materials. Thermally conductive plastics should take a brighter and more important role hereby. The number of E&E applications in terms of automation, linking and other security components is steadily increasing in the future car and especially in the e-mobility. The issue of heat generation and it's effective conduction is a major challenge in many of these applications. But also the field of alternative power drive among others, battery technology has potential for heat conductive plastics, for example in the battery housing, or in other components or in the still cost intensive and complex battery cooling systems. At the same time a wise choice and combination of plastic material and fillers may offer a technically and economically reasonable alternative to metal solutions. The weight reduction helps thereby to optimize the effective reach of the electrical cars.

Additives based on mineral raw material are used in plastics as fillers for many-many years. By adding special mineral fillers with high proper thermal conductivity the thermal conductivity of the polymer can be increased significantly. Furthermore, these additives grant better mechanical strength and better thermal and dielectrical properties in thermoplastics and thermosets. These thermally conductive plastics will find a wide range of current and future applications in the area of electromobility.

Keywords: Thermal management, optimization, battery, cooling, environment

1 Preamble

Well-known for the conductive transportation of heat are metals in various grades and designs. Widely used in the field of passive and active cooling in electronics are aluminium heat sinks, various metallic materials (copper, silicium or even silver) and metallic housings. Only drawbacks are their high price and high electrical conductivities being inevitably linked to the metal properties on which their high intrinsic heat conductivity is based on. An extensive manufacture is needed in almost all cases. The more complex the required geometry, the more difficult it is to make it available. Accordingly, corresponding insulation measures, for example by using an electrically insulating intermediate layer, must be carried out. These and other reasons provide a wide space for the use of new, innovative plastics with improved thermal conductivity.

When being used in combination with electrical components with high energy density (processors, light emitting diodes, electric motors, batteries, electronics etc.) new requirements of an efficient dissipation of heat maintaining electrical insulation properties of housings like integration of heat management/heat sinks are requested.

Generation of heat is inevitably linked to the use of electricity and the resistances involved. Typically heat is an unwanted side effect that has to be kept within certain limits through the choice of materials used and usability of the object itself. Heat reduces e.g. the lifetime of electronics in general. Based on the Arrhenius formula

$$k = A \cdot e^{-(EA/RT)}$$

the Q10-rule of thumb is mostly also applied to the deterioration of electronics by different failure modes, stating, that an increase of 10°C *doubles* the deterioration velocity. Same is true for the oxidation or degradation rates of polymers. This means that lifetime of materials like electronics is cut by half if operating temperature rises by 10°C on the long run [1].

Therefore heat management is an integral part of the construction of electronics, luminaries, electrical parts, parts for combustion engines and other mechanic machines nowadays. Lifetime estimates for LEDs e.g. can only be guaranteed if proper heat transport from the hotspot to air (or alternative cooling systems in high power luminaries) takes place.

2 Mechanism of the thermal conduction

According to the second main law of thermodynamics, the heat flows always from the warmer to the colder side. Heat transfer can be affected through the following three mechanisms:

- Conduction
- Convection
- Radiation

2.1 Conduction

Heat conduction is the energy transport due to nuclear and molecular interdependency. This mechanism is described by the law of Fourier:

$$Q = \lambda * A * (T_{w1} - T_{w2} / d)$$

Q = Heat capacity [W]

λ = Heat conductivity [W/mK]

A = Surface area [m²]

T_{w1} = Temperature of the warmer side [K]

T_{w2} = Temperature of the colder side [K]

d = Thickness [m]

2.2 Convection

At the end the heat has to be discharged. Convection plays an essential role to transport the heat and is independent of the substance. This heat transfer is based on the transport of the particles. Heat release has to be passed by convection (heat transfer from a solid to a moving fluid) to a pool of matter being large enough to take up all that energy released by the heat source on the long run. Heat transfer by convection is described by Newton's law of cooling:

$$Q = \alpha * A * \Delta T$$

Q = Heat capacity [W]

α = Thermal conductivity [W/m²K]

A = Surface area [m²]

ΔT = Temperature deviation between the solid / surface and the fluid medium (Gas or Water) [K]

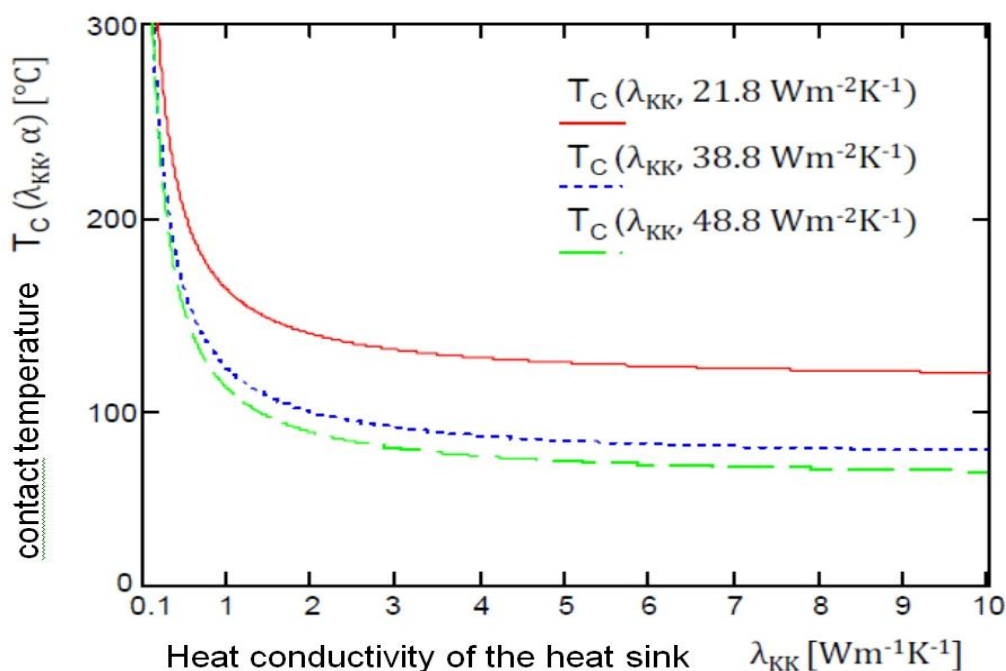
There is a distinction between laminar and turbulent as well as between free and forced convection. Air as a fluid is the most common final destination of that heat. Finally also radiation of every heated part is a direct mechanism of partially releasing heat but less effective when talking about cooling because it can only be influenced by color and texture of the emitter.

Heat transfer coefficients of media in free or forced convection conditions are as follows:

- Air free convection 5-25 W/(m²K)
- Air forced convection 10-200 W/(m²K)
- Water free convection 20-100 W/(m²K)
- Water forced convection 50-10.000 W/(m²K)

Figure 1 [2] shows a graph, revealing, that for effective removal of heat by a heat sink in the regime of free to forced convection of air, heat conductivities of the heat sink exceeding 1W/mK already drastically reduce temperature at the contact area between heat source and heat sink.

Figure 1: Contact temperature in dependence of heat conductivity and convection regimes [1]



In contrast to metal polymers offer complete freedom of design but offering only heat conductivities in the range of 0.2-0.4 W/mK. By using appropriate additives to increase their insufficient heat conductivity polymers will be the future in integrated heat sink/housing design for LEDs as well as for luminaries and other electronic parts. Anyhow new rules of design have to be applied making use of the advantage of creating large surface areas for effective heat transfer to the air as well as reducing the thickness of material in direct contact with the heat source (since velocity of heat transport through the polymer compound material is slower than in metals). Generally the most effective would be a turbulent and forced convection through a liquid medium.

2.3 Radiation

Each and every compound is setting out heat in form of electromagnetic waves starting from 0K (-272°C). Heat radiation is the energy transfer which causes cooling down and heating up of compounds. Cooling by heat radiation is described by the law of Stefan-Boltzmann:

$$P = \sigma * A * T^4$$

P = Radiation efficiency [W]

σ = Stefan-Boltzmann constant [W/m²K⁴]

A = Surface [m²]

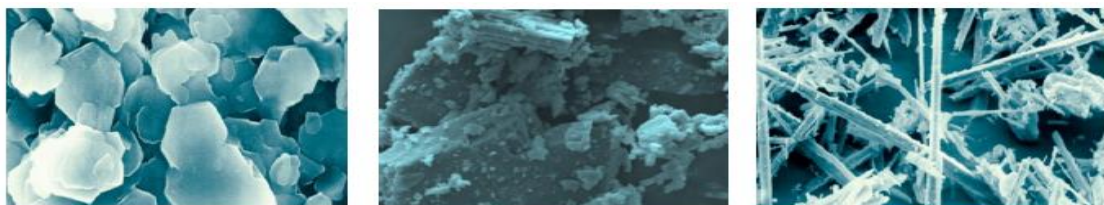
T = Absolute temperature [K]

3 Thermal management of polymers with various fillers

Polymers are insulators (electrical non conductive), and the heat transfer is caused by lattice vibrations, the so called phonons. A phonon is the elementary stimulation (Quant) of the elastic field. The atomic motion is forwarded from neighbour to neighbour because the electrons are fixed to the atom and therefore not able to support effectively the heat transport. This is the main difference to the electrical conductive materials like metals.

For this reason the properties of the fillers regarding the form and size play an important role. The achieved thermal conductivity of the compound and the isotropy itself is influenced by these two aspects besides the proper own thermal conductivity of the filler. As coarser the particle size and as lower the aspect ratio AR (ratio between the length to the diameter or thickness of the particle) is, as higher the improvement of the isotropic thermal conductivity of the finished compound. Picture 1 [3] shows SEM recordings of different shapes and forms of mineral fillers:

Picture 1: Various shapes and forms of minerals [3]



Various properties of the additives play a role in increasing the thermal conductivity in plastics. These can be divided into the material characteristics and the process and product characteristics. Following the influencing variables are listed:

- | | | |
|--|---|--------------------|
| <ul style="list-style-type: none"> - Grain size distribution - Grain shape of the additive - Surface and coating of the filler - Proper heat conductivity - Crystallinity (polymer) | } | Material constants |
|--|---|--------------------|

- Processing
 - Process parameters
 - Filling degree
 - Product design (e.g. wall thickness)
- } Process and product characteristics

To improve the thermal conductivity of polymers, two main groups of fillers can differ, the one of electrical conductive and the other of electrical insulating materials. Hereafter table 1 is showing the commonly used fillers:

Table 1: Thermal conductivity of different materials

Ceramics / Minerals		Heat conductivity λ [W/mK]	Electrical resistance [Ohm*m]
Electrical insulating	Magnesium oxide	30	10^{20}
	Aluminium oxide	30	10^{12}
	Boron nitride	$30 \perp$; (400 \parallel)	10^{13}
	Aluminium nitride	180	10^{15}
	Alumosilicate	14	10^{13}
	Zinc oxide	30	10^{11}
	Zinc sulphide	27	10^{11}
Metal / Other fillers		Heat conductivity λ [W/mK]	Electrical resistance [Ohm*m]
Electrical conductive	Copper	401	1.68×10^{-8}
	Aluminium	235	2.2×10^{-8}
	Iron	80	1.0×10^{-7}
	Graphite	150	2.5×10^{-6}
	Carbon Black	15	5.0×10^{-5}
	CNT (Carbon Nanotubes)	6000	10^3

Nevertheless, independent of the filler, one main rule of thumb is valid in general: More helps more!

That means, in contrast to the electrical conductivity, that as more filler is added to the compound as higher thermal conductivities can be achieved. On the other hand that means also that as higher the filling degree, as higher the influence on the mechanics of the polymer.

Since mechanism of heat conductivity in electrical insulators is driven by the ability of materials to conduct phonons (and NOT electrons) percolation is typically not observed and thermal conductivity is governed by

the amount of heat conductive additive, its intrinsic thermal conductivity, the thermal conductivity of the polymer matrix (which is to some extent governed by its crystallinity) and the presence - or better absence - of interfacial gaps in the setup which are the most critical barrier for heat transfer.

Heinle [2] excellently describes in his work the limits of thermal conductivity of composites with examples from literature:

He states that although carbon nanotubes have an intrinsic thermal conductivity of 3000 W/mK (along their tubular axis) they cannot compensate - at commercially feasible level of addition in the range of below 10% - the volume effect of the polymer matrix. When adding up to 10% of CNT, an epoxy compound does not exceed a thermal conductivity of 0.5 W/mK. Typically thermal conductivities of 1-20 W/mK can be achieved in composites when using high additive concentrations of metals, ceramics or graphite. Highest thermal conductivities cited here are using graphite or copper platelets or filaments in the range of 30-60% by weight. These compounds are *not* electrical insulators.

It is important to find the right balance at the beginning of the development process, between all these aspects. Therefore some issues have to be considered when choosing the appropriate filler:

- Requirements concerning the thermal conductivity
- Thermal expansion
- Mechanics of the compound
- Basic polymer
- Economic feasibility
- Processing
- Costs

4 Optimization of polymer compounds

Additives on mineral base are used as fillers since decades for polymer systems. The mechanics and other special properties of the polymers can be changed, improved or optimized by using such fillers. The addition of special fillers with a high own thermal conductivity can significantly increase the thermal conductivity of the plastics and therefore improve the thermal management of the whole plastic part or component in a unit.

The target field for the investigation was mainly thermoplastic and thermoset material. Hereafter are some explicit results to see the performance of the used fillers in detail and also in comparison to each other exemplary in a polyamide 6 (PA6) and in an epoxy (EP) based compound.

4.1 Investigations and results in thermoplastics

To compare different heat conductive fillers in polyamide, they were compounded at the same heat conductive additive concentration of 65m% in the polymer matrix. Only hexagonal boron nitride gave mechanically completely unstable compounds (no continuous material but unstable aggregates). Therefore additive concentration had to be reduced to 55m% here, being the maximum concentration possible resulting in a material being processable.

Additives were compounded into PA6 by an extruder (Leistritz Co., ZSE27 MAXX). Moldings were produced from those compounds by means of injection molding (Demag Co., Ergotech 100/420-310) of the multi-purpose test bars according to ISO 3167 type A.

Test specimens required for measurement of thermal conductivities were injected. The thermal properties of injection molded parts vary, depending on whether they are measured in flow direction (In-Plane) or in perpendicular direction (Through-Plane) for this purpose. Table 2 shows the results of the mechanical properties and the thermal conductivity of the PA6 compound:

Table 2: Thermal conductivity and mechanics of the PA6 compound with various fillers

65 m% Filler in PA 6	Thermal conductivity		Mechanical properties			Charpy Impact resistance	HDT A
	In-plane	Through-plane	Tensile Stress	E-Modulus	Elongation at Break		
	W/mK	W/mK	MPa	MPa	[%]	kJ/m ²	°C
Coarse aluminosilicate with AST coating	1.5	0.9	92	11100	3.4	37.8	150
Fine aluminosilicate with AST coating	1.3	1.2	94	10000	3.7	42.2	142
Fine zinc oxide with AST coating	1.4	1.0	104	8080	6.2	95.2	119
Aluminium oxide without coating	1.5	0.9	88	9640	3.3	39.1	120
Magnesium oxide without coating	1.4	1.2	84	8910	3.1	31.6	120
Boron nitride without coating	5.3	1.0	68	11800	2.5	10.4	162

Table 3 [1] below shows that heat conductivity in the region of 2.0 – 2.2W/mK is achievable with Aluminosilicate and Zinc oxide maintaining excellent mechanical properties necessary showing the most equilibrated properties:

Table 3: PA6 compounds by varying the Aluminosilicate and Zinc oxide content [1]

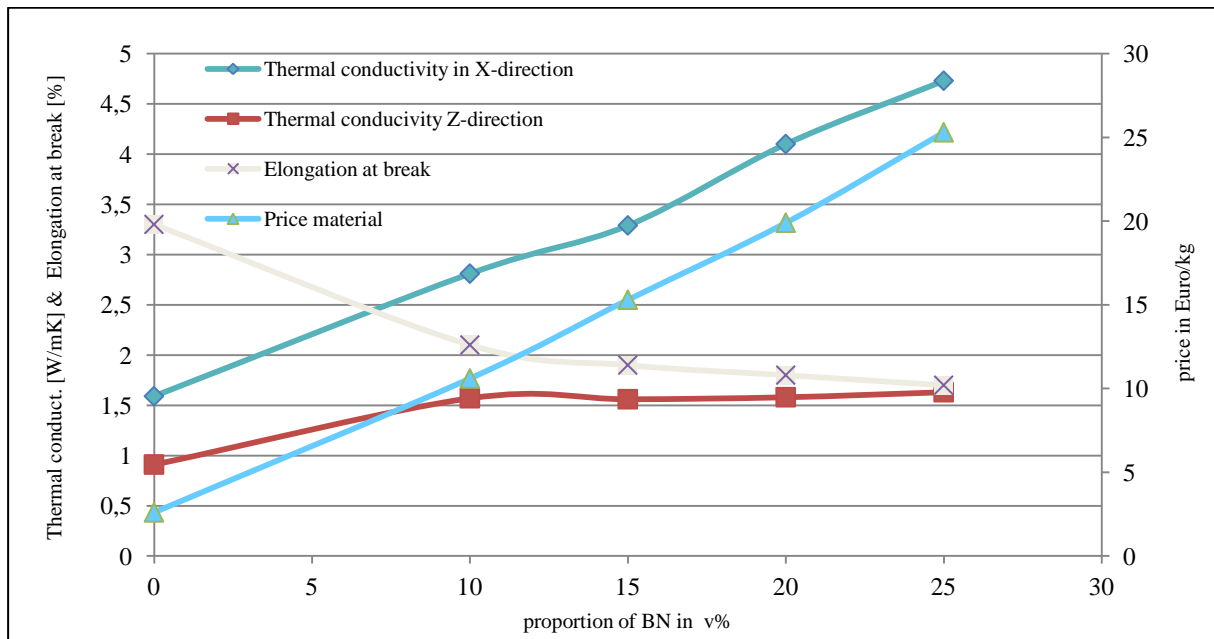
Material	Filling degree [Mas.%]	E-Modulus [MPa]	Tensile stress [MPa]	Elongation at Break [%]	Notched Impact strength [kJ/m ²]
Fine Aluminosilicate with AST coating	65	10000	94	3,7	3,1
Fine Aluminosilicate with AST coating	70	11300	94	3,3	2,8
Fine Aluminosilicate with AST coating	75	15500	95	2,5	2,5
Fine Zinc oxide with AST coating	65	8080	104	6,2	5,9
Fine Zinc oxide with AST coating	70	9350	108	5,4	5,5
Fine Zinc oxide with AST coating	80	13500	116	3,7	3,5

Material	Filling degree [Mas.%]	HDT A [°C]	Thermal conductivity / Through-Plane [W/mK]	Thermal conductivity / In-Plane [W/mK]
Fine Aluminosilicate with AST coating	65	142	1,2	1,3
Fine Aluminosilicate with AST coating	70	143	1,0	1,6
Fine Aluminosilicate with AST coating	75	164	1,3	2,0
Fine Zinc oxide with AST coating	65	119	1,0	1,4
Fine Zinc oxide with AST coating	70	136	1,2	1,4
Fine Zinc oxide with AST coating	80	162	1,7	2,2

Therefore the use of the material not only as heat sink but also as exterior housing with integrated heat sink function is possible. It becomes clear that heat conductive additives differ heavily in price and performance. Performance must never be measured by heat conductivity alone but also mechanical properties have to be taken into account especially for housings or heat sinks.

If even higher values are required an interesting combination between fillers could offer the solution. It has already been reported that adding small quantities of hexagonal boron nitride to an Aluminosilicate/PA-compound can increase heat conductivities without deterioration of mechanical properties and with only moderate effect on the price. Figure 2 [4] shows this example of a hybrid-filler solution:

Figure 2: Combination of Aluminosilicate with boron nitride in PA6 [4]



4.2 Investigations and results in thermosets

In addition to the thermoplastic system, different grain sizes, surface coated grades of Aluminosilicate and Aluminium oxide were tested in epoxy application. During the investigation also new bi- and tri-modular grain size distributed types were reviewed. Few main aspects of the final resin are in focus:

- Viscosity
- Mechanics
- Thermal expansion
- Electrical properties
- Heat conductivity

An epoxy resin system (resin: ARALDITE CY 184, hardener: ARADUR HY 1235, accelerator: DY 062) has been filled with different grades of Aluminosilicate and Aluminum oxide additive (SILATHERM[®] and SILATHERM[®] Plus grades) and tested regarding thermal conductivity and mechanical properties. The compound was mixed under vacuum at 60 °C. Conditions of the curing process were: 2 h at 100 °C and 16 h at 140°C post cure. For each sample five specimen (12,7 x 12,7 x 2 mm) were analyzed.

For the determination of thermal conductivity of filled epoxy resin a NETZSCH LFA 447 NanoFlash according to ASTM-E-1461, DIN 30905 and DIN EN 821 was used.

Although the goal of the developments was to increase the filling degree, at the same time easy process ability (casting) remained always in focus. With a new special surface treatment in combination with the perfect grain size distribution, an equilibrated compound in view of thermal conductivity, processability and mechanical data could be developed.

Cast epoxy resins are often used to encapsulate electric components which are made out of metals with low coefficient of thermal expansion (CTE) values ($23 \cdot 10^{-6}$ 1/K, Aluminium, $16.5 \cdot 10^{-6}$ 1/K Copper) For that reason during the investigations also the CTE of the whole system was tested.

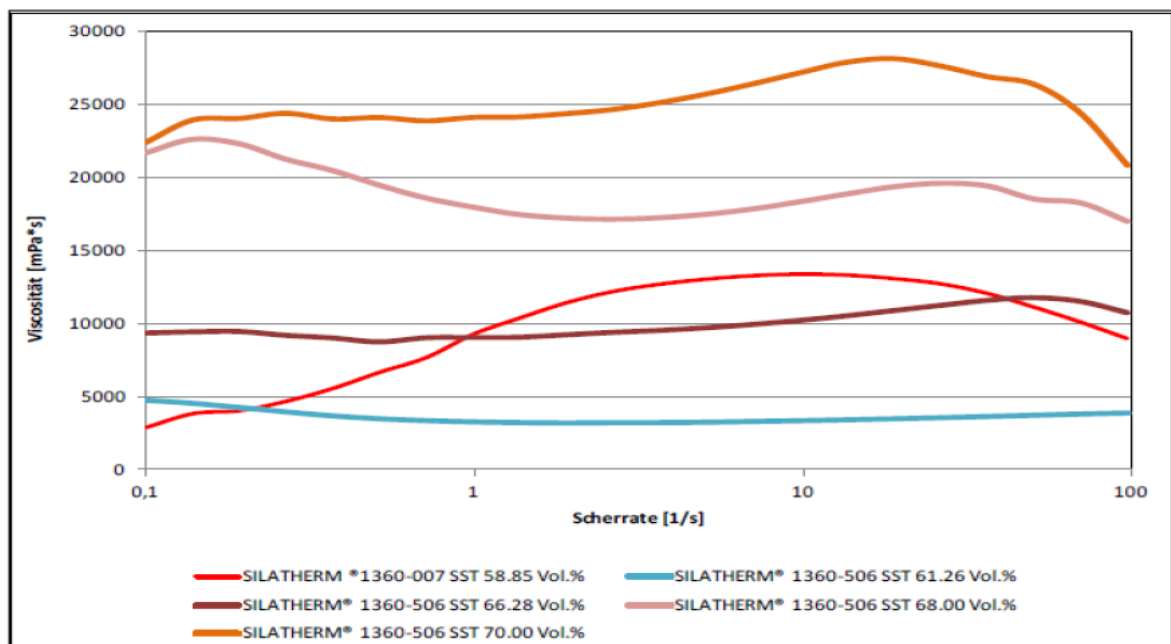
Mechanical properties of the Alumosilicate with different filler loadings and surface coatings of the mineral are shown in Table 4 below:

Table 4: Mechanical properties of an epoxy system filled with Alumosilicate

Filler	Filler load [Vol.%]	Filler load [Wt.%]	E-Modulus [MPa]	Flexural strength [MPa]	Elongation at break [%]	Impact strength [kJ/m ²]
SILATHERM® 1360-007 SST	58.85	81.00	19010	107	0.62	5.50
SILATHERM® 1360-506 EST	58.85	81.00	23120	145	0.77	8.89
SILATHERM® 1360-506 EST	61.26	82.50	27591	145	0.63	8.12
SILATHERM® 1360-506 SST	61.26	82.50	33100	134	0.49	6.25
SILATHERM® 1360-506 SST	66.28	85.42	34140	141	0.50	7.03
SILATHERM® 1360-506 SST	70.00	87.42	36260	131	0.42	5.41

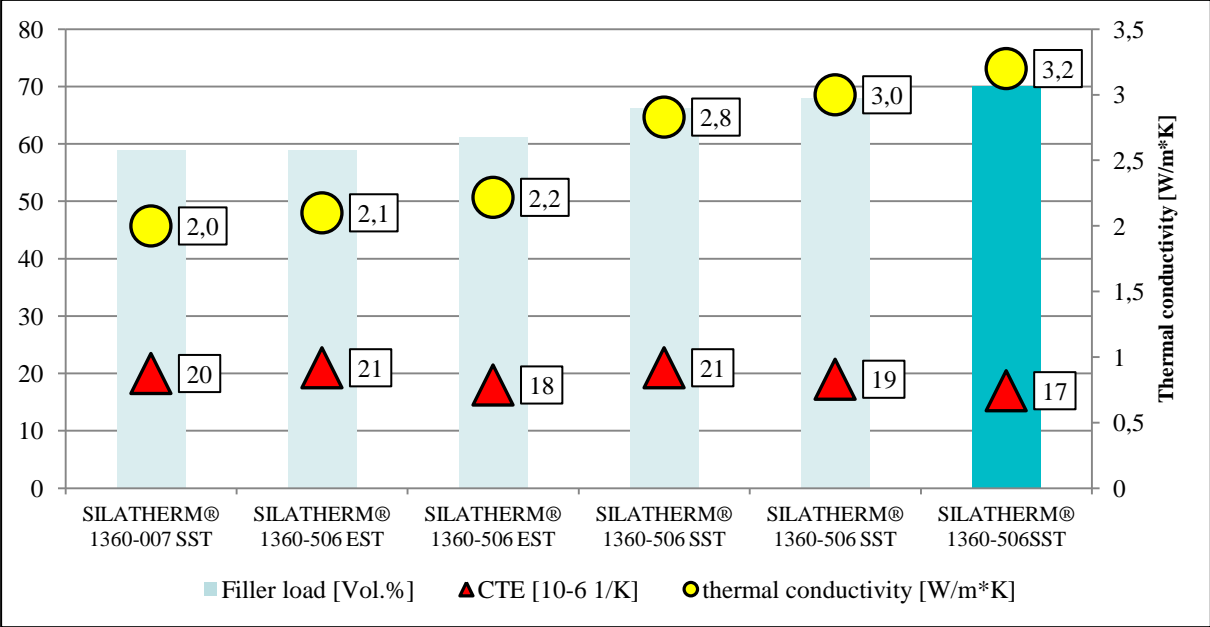
Viscosity properties of the cast epoxy resin are automatically influenced by high filler loadings. Figure 3 shows the viscosity as a function of the filling degree and the surface treatment of the mineral:

Figure 3: Viscosity curves of the epoxy resin filled with alumosilicate



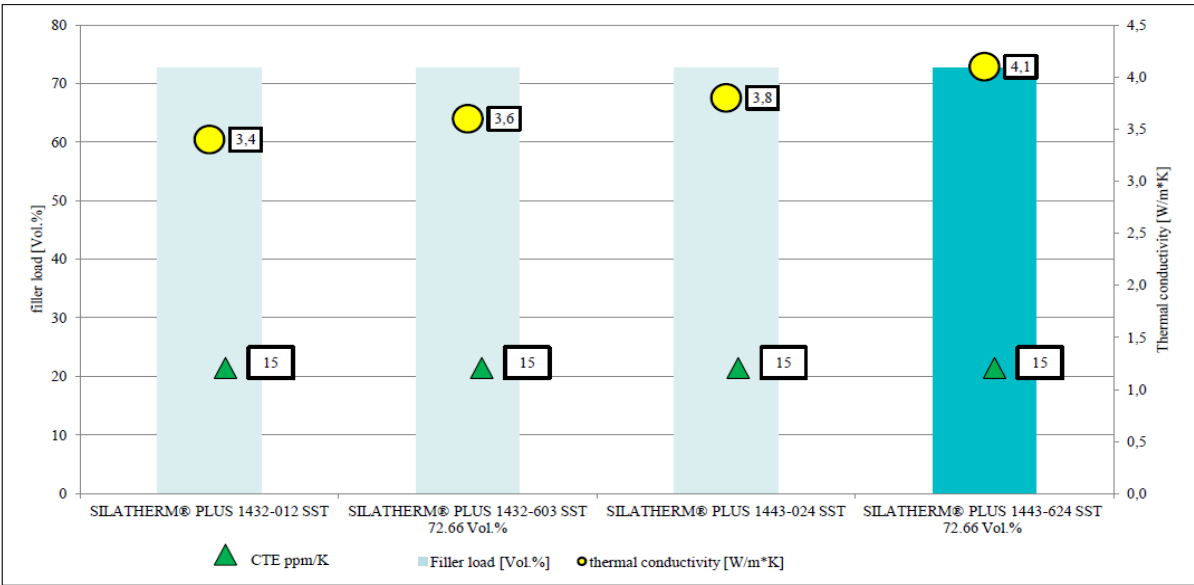
Heat conductivity and thermal expansion was improved step by step using different coatings, different grain sizes and different filling degrees of the Alumosilicate in the final epoxy resin. The thermal conductivity could be increased by more than ten times and the CTE is below of aluminum and almost on the level of copper. The results are shown in Figure 4 below:

Figure 4: Heat conductivity and CTE of the epoxy resin with Alumosilicate



In the next step the investigation with Aluminum oxide were carried out the same way in an epoxy compound. The filling degree and therefore also the thermal conductivity could be further optimized by the grades with bi- and tri-modular grain size distribution based on Aluminum oxide and the optimization of the surface treatment has a positive effect on the viscosity of the thermoset. In the course of the experiments, it turned out quickly that a maximum filling degree makes a significant contribution to increasing thermal conductivity. Values of over 4 W/mK were achieved, by keeping the viscosity on a processable good level with the special SST treatment. The CTE of the epoxy resin was reduced to a value of 15, which is quite similar to copper. The results are summarized in Figure 5:

Figure 5: Heat conductivity and CTE of the epoxy resin with Aluminum oxide as a function of the filling degree and the surface treatment



5 Application examples for the use in E-Mobility

5.1 In general

There are already a large number of current applications in the automotive sector which are made out of plastics. Thermoplastics and thermosets are widely used for example in E&E (electric and electronic) applications. Their low thermal conductivity in the range of only 0.2-0.4 W/mK is linked to their chemical structure. There are a couple of good and meaningful reasons and current requirements for increasing the thermal conductivity of already used polymer based materials:

- Improved performance of various applications
- Downsizing of electrical components
- Economical use of waste heat
- Added appearance of warmth
- High costs for cooling
- Raise of the power output
- Extension of life period

The increasingly higher and more complex connectivity of the vehicles requires a large number of E & E applications. This is a wide range of applications such as switches, electrical control units, sensors, shielding, cabling components or even electric engines.

Other automotive applications, such as plug-in connections, housings and not least the increasing number of LED lighting systems in the interior and in the exterior, opens up new and innovative possibilities for thermally conductive plastics.

Future components in the driving systems of electromobility (battery) are also interesting fields of application. In some of the applications, waste heat may be economically and technically useful. At the same time, the heat dissipation inevitably leads to an improvement in service life, better sustainability and thus an optimization of the product.

5.2 Battery cooling / Case study of a heat sink

Within all of the developments in the area of E-Mobility the thermal management of the battery is one of the most observed topics. An optimal working temperature for the battery is a requirement concerning the durability, the efficiency and the life time of the battery. Therefore an extensive cooling is indispensable and current systems are often complex and cost intensive to realize this matter. In this context the use of a thermal conductive polymer has already been considered in a couple of development projects for battery housings designed with plastic materials, for example, when an exterior housing with integrated heat sink function is possible.

Hereinafter a simulated comparison of two heat sinks, one out of aluminum and one made of a polymer filled with alumosilicate, is described. The heat sink had the same geometry for the 1:1 comparison. To each heat sink a metal block as substitute for an electronic part was glued with heat conductive glue and both assemblies were put onto a hot plate heated to 100°C isolated versus the surroundings. Picture 2 shows the set up with the EP/Alumosilicate heat sink in front:

Picture 2: Experimental setup of heat sink comparison



Measurements of temperatures took place at the metal substitute for the electronics as a direct indicator of the heat dissipation by the heat sink as well as on the lower part of the heat sink by an infrared camera. Experiments were performed under different convection conditions:

- Full free convection of air with approx $5W/(m^2K)$ (closed environment),
- Free convection of air with approx. $25W/(m^2K)$ (open environment) and
- Forced convection of air with approx. $100W/(m^2K)$ (fan blowing onto heat sink).

Figure 6 (a, b): Temperature over time of polymer composite and aluminum heat sink respectively their metal support (as substitute for the electronics to be cooled) under free convection (approx. $5W/(m^2K)$)

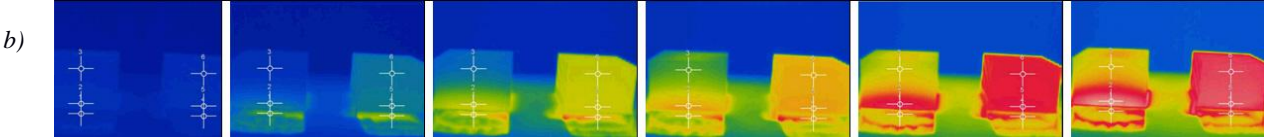
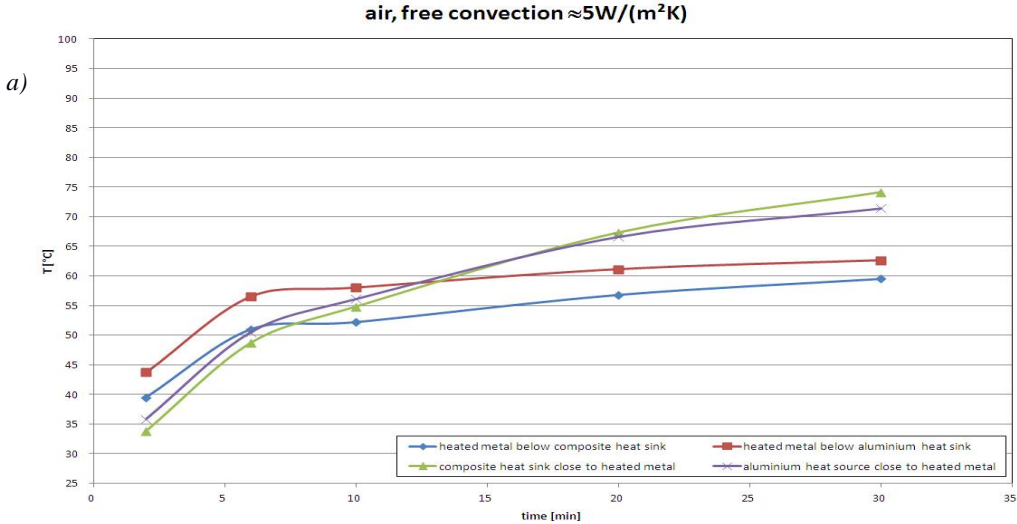


Figure 7 (a, b): Temperature over time of polymer composite and aluminum heat sink respectively their metal support (as substitute for the electronics to be cooled) under free convection (approx. $25W/(m^2K)$)

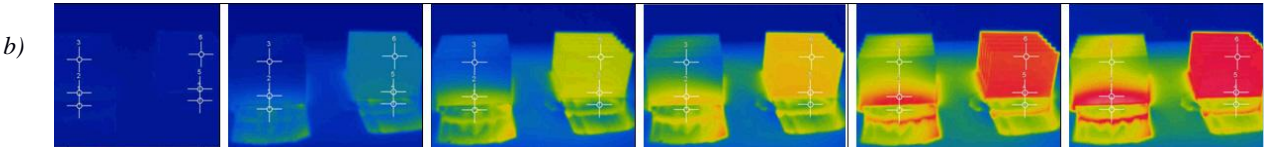
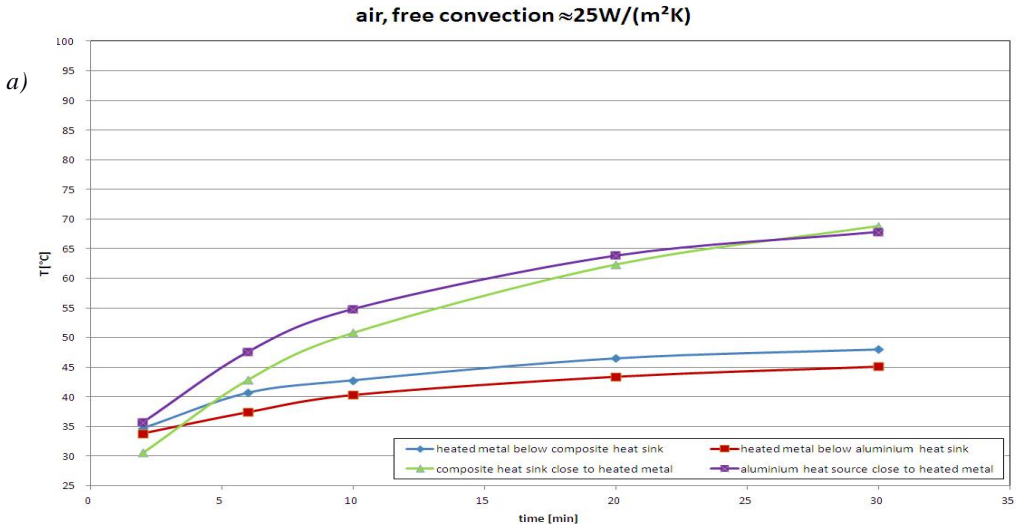
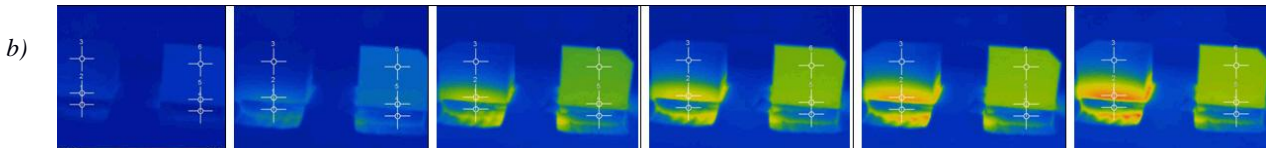
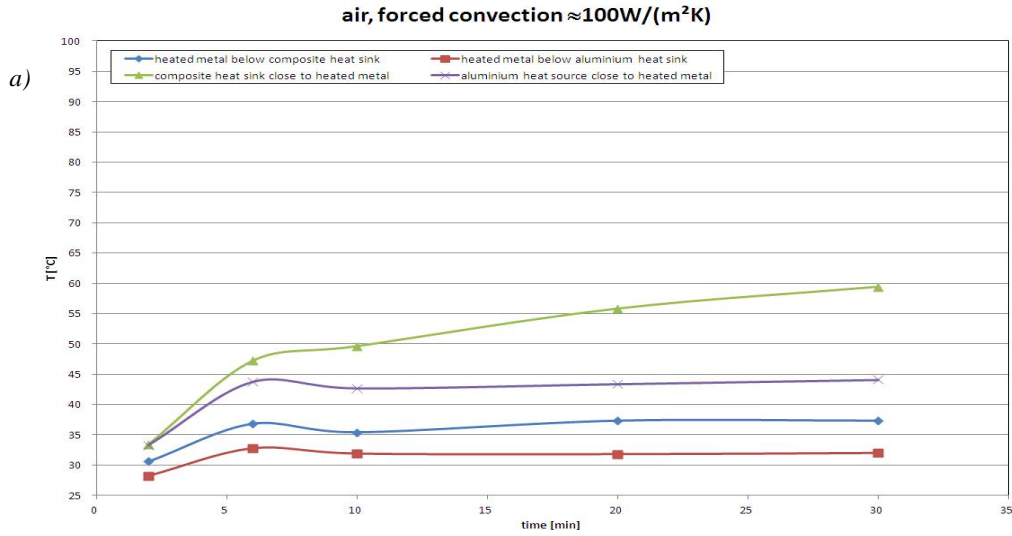


Figure 8 (a, b): Temperature over time of composite and aluminum heat sink respectively their metal support (as substitute for the electronics to be cooled) under forced convection (approx. $100\text{W}/(\text{m}^2\text{K})$)

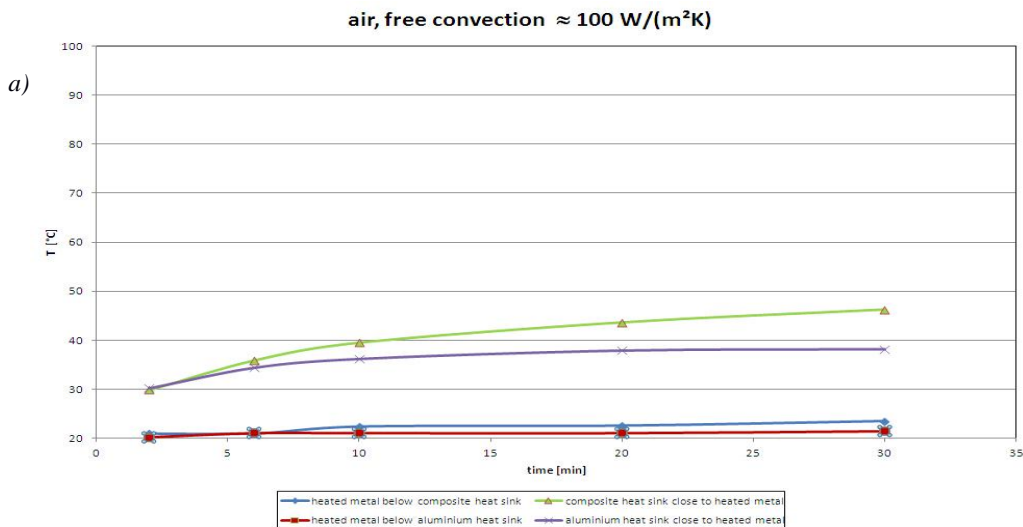


In the regimes of free air convection the composite heat sink shows the same performance as the aluminum metal heat sink, keeping the metal block (the “electronics”) at the same temperature.

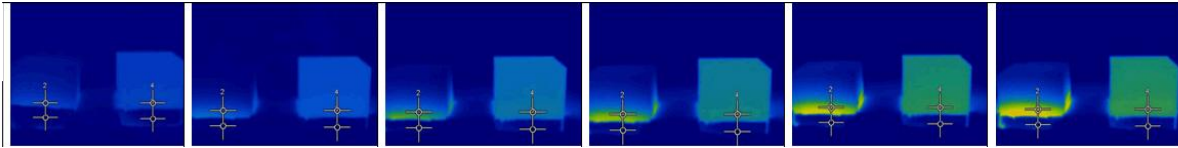
In the regime of forced convection the composite heat sink keeps the “electronics at 37°C whereas the aluminum heat sink keeps it at 32°C – nevertheless it should be kept in mind that the “electronics” was heated to 100°C by the hot plate from below.

Finally new rules of construction for heat sinks made of plastics were applied like reducing the thickness of material in direct contact with the heat source (since velocity of heat transport through the compound material by nature is slower than in metals). Even more improvements are achieved as shown in figure 9 (a, b) in comparison to figure 8 (a, b).

Figure 9 (a, b): Temperature over time of composite and aluminum heat sink respectively their metal support (as substitute for the electronics to be cooled) under forced convection (approx. $100\text{W}/(\text{m}^2\text{K})$) with reduced material thickness on the composite heat sink base.



b)



Here the metal plates as replacement for electronic parts kept cool both at the same temperature and both at about room temperature. At the same time the weight of the heat sink was reduced by 30% (Alumosilicate/EP = 62 g, Aluminum = 88g) and the CTE of the Alumosilicate/EP heat sink with (CTE = 25) was on the same level like the one made out of Aluminum (CTE = 23).

This simple experiment shows impressively the achievable results with thermally conductive polymers in comparison to Aluminum and the idea of changing a design of the part. Furthermore the important influence of the convection as one of the main mechanism of heat transport described in chapter 2.2 previously is shown.

6 Environment

The consideration of the carbon footprint is not just a marketing tool these days as it shows the pursuit of preserving the environment and makes therefore middle and long term perfectly sense for all producing companies. Table 5 shows the results according to some sources:

Table 5: Comparison of the carbon footprint of 1to produced material

Material	GWP [CO ₂ eq]	Source
Mineral	0,12 to CO ₂ / 1 to Product	Life Cycle Inventory (LCI) from Industrial Minerals Association (IMA-Europe) Feb 2013
Aluminium	11 - 16 to CO ₂ / 1 to Product*	Global Life Cycle Inventory Data for the Primary Aluminium Industry” (2013) Life Cycle Impact Assessment (LCIA) results for the worldwide aluminium industry
Polyamid 6	6,7 to CO ₂ / 1 to Product	Eco-profiles and Environmental Product Declarations of the European Plastics Manufacturers, Polyamide 6 (PA6), Plastics Europe, February 2014

* Value depending on the region

Comparing the production of one ton of Aluminium with the production of one ton of a polymer (exemplary PA6) composite filled with minerals the carbon footprint is almost by a factor of 6 better than aluminium.

7 Conclusion

The increasing desire for higher integration levels and downsizing of functional components requires the use of novel plastics for the realization of highly functional system solutions. Thermally conductive plastics open up the possibility of realizing the mechanical component, the function for heat dissipation and the electrical insulation in one automated production step. Freedom of design and the great integration potential of plastics are combined with the effective heat dissipation and homogeneous temperature distribution. The thermal conductivity of the resulting molded part can be deliberately controlled by the targeted selection of the filler system, the component layout and processing in the injection molding process. The material synergies can be exhausted optimally.

The use of mineral fillers can be used to modify the property profiles of plastics. The results clearly show a significant increase of the thermal conductivity having still good mechanical properties in various polymer

systems by using mineral fillers. Values of 2.2 W/mK in thermoplastics and up to 4 W/mK in thermoset materials are achieved. With a kind of hybrid filler system even higher conductivities are possible, so further applications with higher thermal conductivities can be targeted.

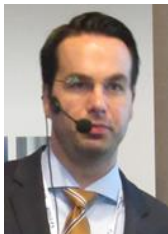
This results in new and exciting fields of application for such modified materials. Thermal management and the potential applications in the field of electromobility are ideal areas for thermally conductive plastics for current and future requirements. As with other materials, the advantages and disadvantages must be considered, weighted and taken into account in the concept (design and construction) at the beginning of a development process. Thus, the predominant advantages of such fillers, such as significant increase in thermal conductivity, moderate effect on the mechanics of the compound compared to other fillers, isotropy, good bonding to the plastic matrix, increase of heat resistance, etc., can be optimally used.

Summarized we can say, that the use of thermally conductive plastics creates a whole series of important advantages. Besides the benefits of lightweight construction the use of plastics offers the possibility of producing complex geometries quickly and cost efficiently by means of injection molding or casting technologies. This new development will influence heavily forthcoming solutions in electronics, electrical devices, and also but not exclusively within the e-mobility.

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