CONDUCTIVE POLYMERS FOR METAL REPLACEMENT
LFA analysis and its applications for the development of innovative raw materials

Thermal and electrical conductivity are two fundamental properties for the development of technical polymers for the design of components traditionally made with metal alloys.
For the study of the thermal conductivity of polymers and how it varies as a function of charge orientation, Light Flash Analysis (LFA) has numerous advantages as a fast and reliable technology.

This article presents some of the results of DOMO Engineered Materials (EM) R&D on the development of highly customised thermo-conductive solutions based on polyamides and the collaboration with NETZSCH Gerätebau GmbH on the extended study of these formulations using the tool LFA 467 HyperFlash®.

NETZSCH
Proven Excellence.

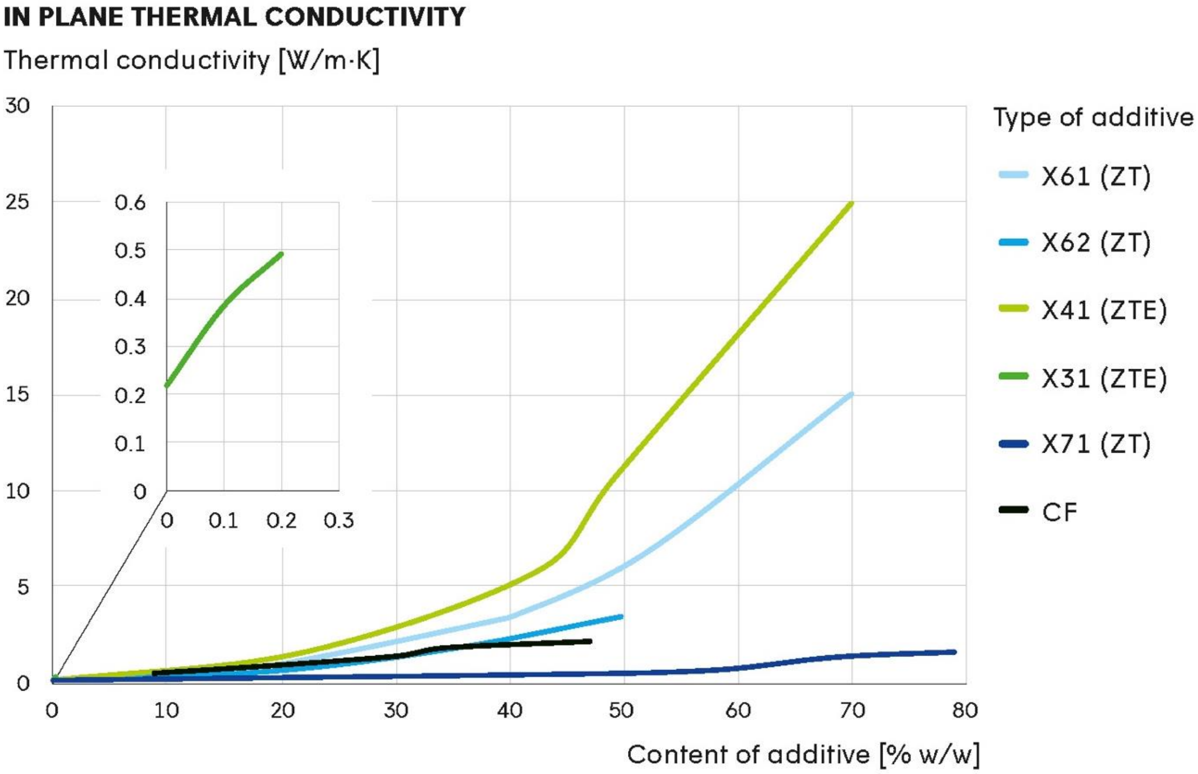
Picture LFA 467 HyperFlash®

In the field of heat transfer there are two options, thermally conductive and electrically insulating materials or thermally and electrically conductive materials. DOMO EM identifies the former as DOMAMID® ZT and the latter as DOMAMID® ZTE. In both categories there are both isotropic and anisotropic materials.
This project began in 2017 when DOMO R&D started an analysis of the various additives that can give polyamides this kind of characteristic. Another key aspect was the choice of thermo-conductivity measurement methodology, specifically the Light Flash method, and in particular the LFA 467 HyperFlash® instrument from NETZSCH. To date, several formulations have been deployed and many important projects in the automotive industry are in the final stages.

This segment of conductive materials in particular demands very high customisation, as the conductivity of the material depends as much on the additives used as on the geometry of the final application. Several additives were considered during the study, mainly carbon-based such as carbon black, graphene and graphite, but also inorganic materials such as alumina and boron nitride.

© DOMO Engineering Plastics Europe

Graph 1.1, which shows the measurement of the in-plane specimens, clearly presents the way in which thermal conductivity (TC) levels on a PA6 material vary with the various fillers used and their quantity. A significant increase in conductivity is observed only above 40% filler.

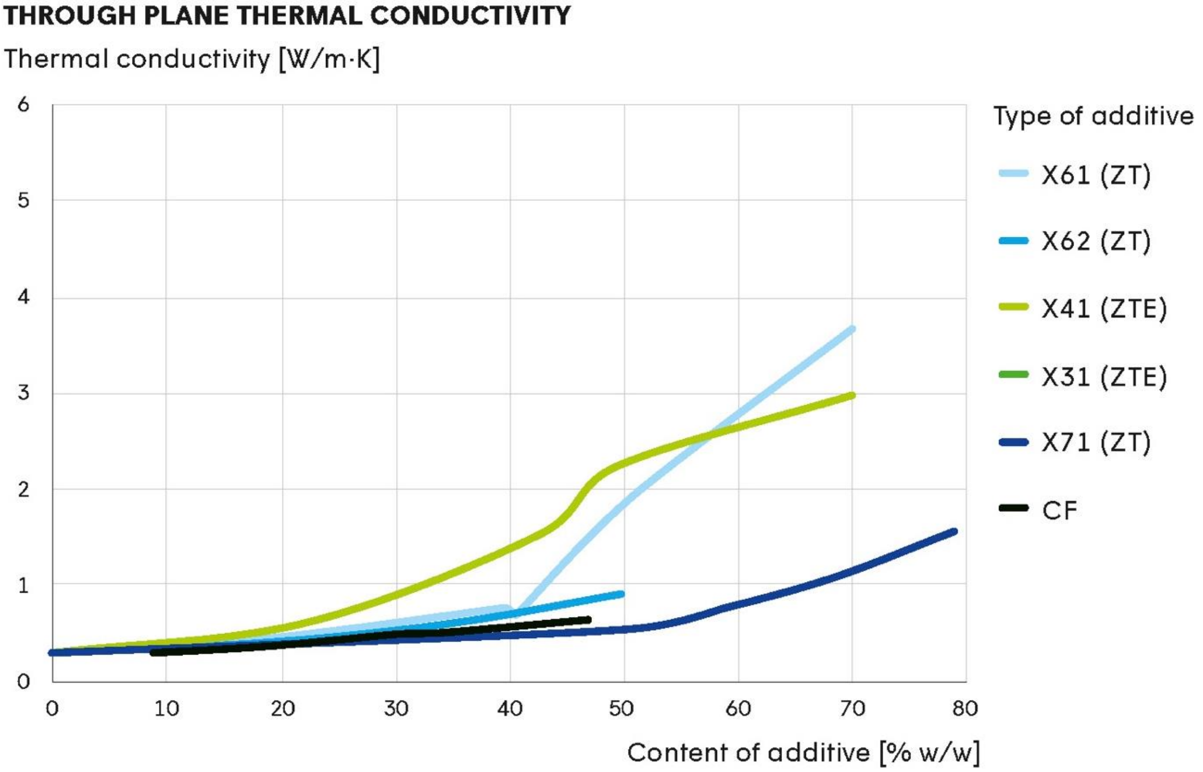


© DOMO Engineering Plastics Europe

Graph 1.1

The maximum conductivity value depends on the characteristics of the filler and indeed a significant variation in the composition of the overall filler (sample X61 and X62) can give rise to very different TC values. The fillers shown to be most effective are Boron Nitride and Graphite. In addition, it is found that the TC values measured "in plane, in flow direction" are generally the highest for anisotropic materials.

Graph 1.2, on the other hand, presents the CT measurement with "through plane" technology. It is clearly shown that for anisotropic materials the values of TC "through plane" are generally lower than those obtained "in plane”. This is due to the different arrangement of the filler within the sample, given the actual geometry of the particles. In isotropic materials (X71), by contrast, the TC values are equal in the three spatial dimensions.

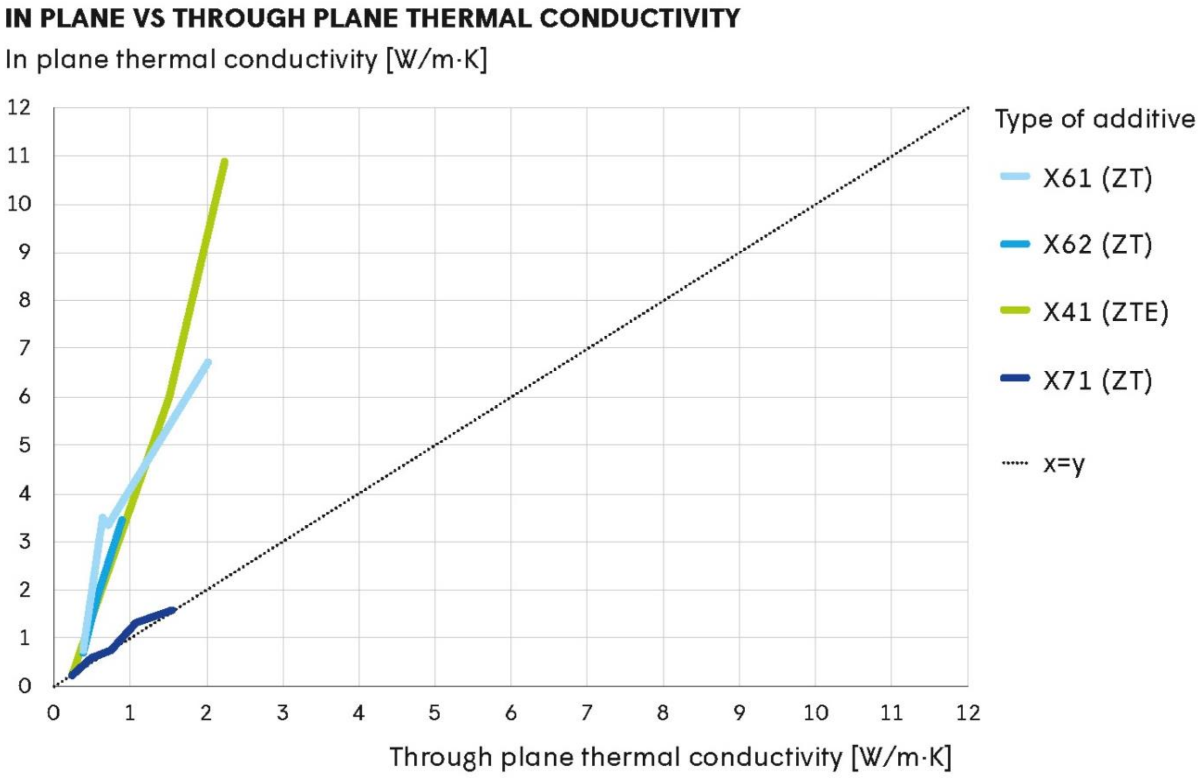


Graph 1.2

© DOMO Engineering Plastics Europe

Boron Nitride and Graphite are confirmed to be the most effective fillers in this measurement as well.

Graph 1.3 summarises the results of both previous measurements. As can be seen, isotropic materials show TC values close to the bisector of the quadrant, while anisotropic materials show values far from the axis. The more the values deviate from the x=y axis, the more the material has anisotropic behaviour.



Graph 1.3

© DOMO Engineering Plastics Europe

This behaviour confirms that the choice of material and which filler to use will therefore depend largely on the design and geometry of the final part. The value of the thermal conductivity of the material cannot and must not be the only selection criterion.

The LFA method (LFA 467 HyperFlash® from NETZSCH) was chosen because of the simplicity with which, with this instrument, it is possible to measure thermal conductivity both "through plane" and "in plane". In fact, the measurement is always taken in the same way. Just cut the square sample used for the measurement "through plane" into strips and rotate them 90 degrees, recomposing the sample in the square shape and reinserting it in the special sample holder for laminates. Physically the measurement will always be "through plane" with respect to the sample holder, but the rotation of the plates inside the instrument enables us to obtain data relative to the conductivity "in plane".

The additives currently approved for thermally conductive and electrically insulating materials (DOMAMID® ZT) are Boron Nitride and Alumina, mixed in various combinations. For DOMAMID® ZTE solutions, on the other hand, i.e. for thermally and electrically conductive materials, the additive mainly used in DOMO formulations is graphite.

Table 1.4 shows that the metals used to provide the application with a certain degree of thermal conductivity are often oversized. The same objective can be achieved with a material of much lower thermal conductivity.

COMPARISON OF THERMAL CONDUCTIVITY OF PLASTICS AND METAL

	FREE CONVECTION				**FORCED CONVECTION**			
	Standard plastics	Thermal conductive plastics		Metal	Standard plastics	Thermal conductive plastics		Metal
Energy/heat Q [W]	3	3	3	3	15	15	15	15
Thermal transmittance h [W/m²·K]	7	7	7	7	50	50	50	50
Thermal conductivity k [W/m·K]	0.1	2.0	10.0	100.0	0.1	2.0	25.0	100.0
Temperature T_1 [°C]	120.5	120.5	120.5	120.5	118.4	118.4	118.4	118.4
Temperature T_2 [°C]	142.0	122.9	120.9	120.5	264.1	134.3	121.0	118.5
Temperature difference ΔT [°C]	21.5	2.4	0.4	0.0	145.7	15.9	2.6	0.1

Tabel 1.4

© DOMO Engineering Plastics Europe

The left part of the table illustrates a case in "free convection". If we assume an LED represented as plane A, on which a specific power source (q) is active (Figure 1.5), and fix as a limit to be reached on the opposite surface the temperature of 120.5°C, we see that aluminium, one of the metals mainly used in these applications, with a conductivity of 100 W/mK, is clearly oversized. In order to guarantee the same level of protection and temperature maintenance, a plastic material with 10 W/mK would be sufficient to achieve a very similar result. The data also show that a material with conductivity of only 2 W/mK would be sufficient for the same application.

If, on the other hand, we move to a case of forced convection, a higher level of thermal conductivity would probably be necessary. In that case, the geometry of the part and its consequent requirements would also have to be reconsidered.

THERMAL CONDUCTIVITY IN A HEAT SINK

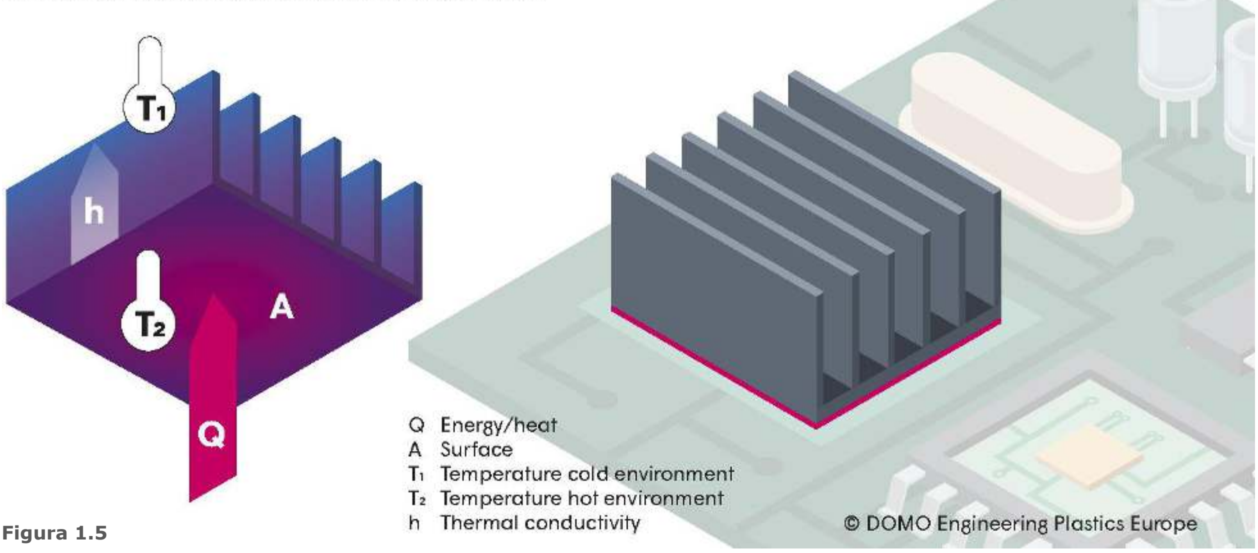


Figura 1.5

Thermally conductive technical polymers have countless advantages over metals. The main ones are greater flexibility and efficiency. With a plastic material we increase the possible geometries of the mould, reduce cycle times and avoid many post-treatments which are required with metallic materials.

Plastics avoid the corrosion problems characteristic of metallic materials and have lower density than metals, lightening the weight of the final application.
Simply bear in mind that a polyamide weighs up to 33% less than aluminium, contributing, especially in vehicle applications, to reducing the weight of the vehicle, with consequent lower fuel consumption and C02 emissions into the atmosphere. In addition, a plastic component can significantly reduce vibrations compared to metal elements.
The use of different bases can meet different requirements in terms of additional characteristics for our material, such as good processability, chemical resistance, flame resistance and adequate mechanical properties.

The target applications of these materials are heat sinks, coolant management systems, LED lighting systems, parts for miniaturisation in electronic systems and a range of automotive applications.
Two important case histories we have developed come from the automotive sector, which is one of our main markets.

In the first case, we developed a solution for printing an engine cover for an electric vehicle. The specifications required in this project were long-term heat resistance, chemical resistance, excellent processability and thermal conductivity.

The material approved by Tier 1 was a PA6-based, heat-stabilised material with thermal conductivity of 1.2W/mK (DOMAMID® ZT 6X70H1 X71 NC91).

The second case considered by this study is also for an under-the-hood application, as part of the cooling circuit of an electric motor.
The requirement was for a thermally and electrically conductive material. The customer provided some thermal conductivity data "through plane" equal to or greater than 2.5 W/mK. The application required high fluidity due to the reduced thickness and dimensions of the mould (component thickness 1mm and length 50mm), heat stabilisation capable of withstanding peak temperatures around 210 °C and good mechanical properties identified by a maximum break stress of about 70 Mpa.
The approved solution for this particular application was a PA66-based, heat-stabilised grade with a thermal conductivity of 2W/mK "through plane" and 12W/mK "in plane" (DOMAMID® ZTE 66X50H1 X41 NC99)

KEY TAKEAWAYS

DOMO presents its know-how in the development of highly customised thermo-conductive solutions based on polyamides and its collaboration with NETZSCH in the extensive study of these formulations with the LFA 467 HyperFlash® tool.

DOMO offers a customised portfolio of thermally and electrically conductive technical polymers based on PA 6, 66 and PPS, which can guarantee:
- Adequate chemical resistance.
- Flammability in line with FMVSS302 automotive standards.
- Adequate mechanical performance.
- Choice of electrical insulation or electrical conductivity
- Longer component life.
- Corrosion resistance.

DOMAMID® Z is the brand name for the thermally conductive solution.

The most significant target applications for these products are heat sinks, LED lighting and fluid management systems.

DOMAMID® Z solutions can replace aluminium, allowing the lightening of the final application by more than 30%. In particular, in the automotive sector, this translates into lower fuel consumption and lower CO2 emissions. A further benefit of DOMAMID® Z materials compared to metals lies in their ability to dampen vibrations.

The key advantages of DOMAMID® Z over metal are:
- Greater freedom of design.
- Reduced weight.
- No need for post-treatment.
- Increased durability of the final component and improved processability.
- Colourability.
- Vibration and noise dampening.
- Integration of functions.

DOMO Engineering Plastics Europe S.P.A.
Via Linfano, 18 | 38062 Arco (TN) | Italia

www.domochemicals.com