Changing thermal conductivity of plastics with thermal conductive fillers

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Introduction

Thermoplastic materials have benefits like easy processing into various shapes, good cost-property-balance and a high degree of freedom in regard to the property combinations. One of the few drawbacks of thermoplastics is their limited thermal conductivity, which can be an issue in some applications, where this is necessary for thermo-management of components like electronics. While the parts directly contacting an electronic part need to be electrically insulating for obvious reasons, further cooling devices do not necessarily need to be electric insulators. Therefore, the aim of this work was to improve the thermal conductivity of selected plastics with the addition of particles and assess these changes in thermal conductivity with the hot disc TPS2200.

Materials & Methods

For this work, a polypropylene homopolymer (PP), a polyamide (PA) as well as a polycarbonate (PC) were selected as the base polymers. All three were general purpose grades intended for injection moulding.

As the fillers, two metal powders (aluminium and copper) as well as a graphite powder was used. The size and shape of these can be seen in Fig. 1. While aluminium was the coarsest powder (200 – 800 µm), copper powder was smaller than that (100 – 250 µm) and graphite was the smallest (5 – 20 µm).

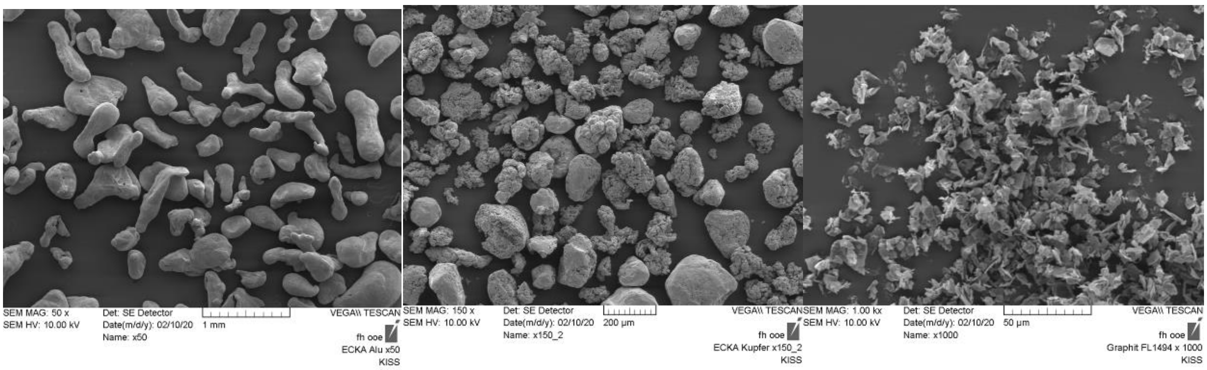

Figure 1: Aluminium particles (left), copper particles (middle) and graphite powder (right) used in this work; be aware of the different scale bars for the three materials

These fillers were mixed with the different polymers in a range of 0 – 50 wt% with a co-rotating twin screw extruder. The granules yielded from this were dried and afterward moulded into universal test specimen. Parts from these (the shoulder parts) were used to sandwich the sensor of the Hot Disk TPS 2200 and to run the thermal conductivity measurements (Fig. 2).

Figure 2: Extruded melt strands (left), granules with graphite (middle left), injection moulded test specimen (middle right), Hot Disk measurement setup (right)

Results

The thermal conductivity of the different samples was measured at room temperature. For each sample, three replicates were evaluated. Special attention was given to that the surface was clean and the impressions from the ejector pins were on the opposite sides. The results in the protocol for such a set of samples can be seen in Fig. 3.

Ergebnisse:

	λ	α	cp	s	ΔT	ΔT ges.
1	0,5187 W/mK	0,6615 mm²/s	0,7842 MJ/m³K	3,54 mm	0,635 K	1,94 K
2	0,5192 W/mK	0,6646 mm²/s	0,7812 MJ/m³K	3,55 mm	0,635 K	1,93 K
3	0,5191 W/mK	0,6622 mm²/s	0,7839 MJ/m³K	3,55 mm	0,635 K	1,94 K
Mittel	0,5190 W/mK	0,6628 mm²/s	0,7831 MJ/m³K	3,55 mm	0,635 K	1,94 K

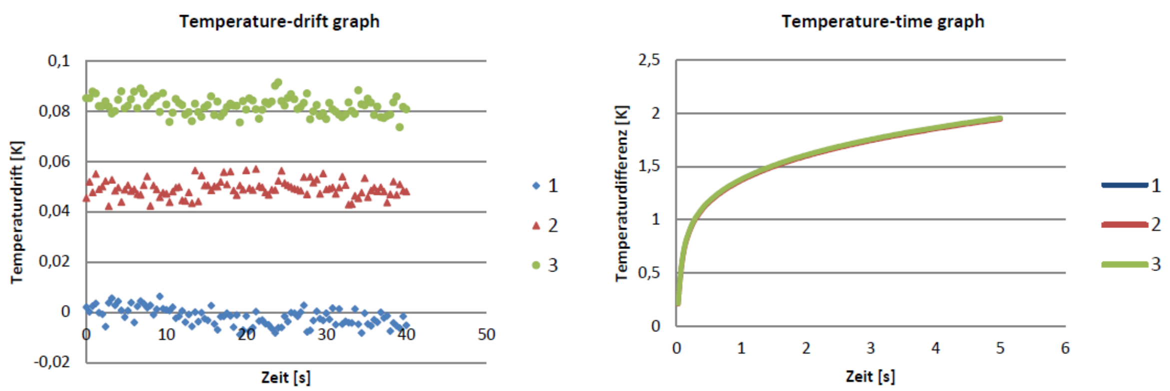

Figure 3: Example for a measurement protocol from the Hot Disk TPS 2200

The results from these measurements were then plotted for the different polymers versus the volume fraction of the fillers (as the properties of such composites always correlate via the volume fraction). Also, for better comparison, the thermal conductivity was related to the value of the virgin polymer, which was also measured with the Hot Disk. The results for PP and the different fillers are shown in Fig. 4. One can see, that with increasing filler content, the thermal conductivity is increasing. This was expected, as the virgin PP exhibits a thermal conductivity of 0.23 W/mK, while copper, aluminium and graphite all show values of at least over hundred W/mK. The increase is linear in the first region, but then it gets steeper, as the particle-particle interactions are increasing (Fig. 5), thus improving thermal conductivity, as less PP layers are present in the thermal pathway. Also, graphite gives better improvement than both the metal powders, which can be accounted to the shape and size of graphite. As these are flakes (in contrast to elongated spheres) and much smaller, the effect found here is higher due to the higher specific surface of the graphite.

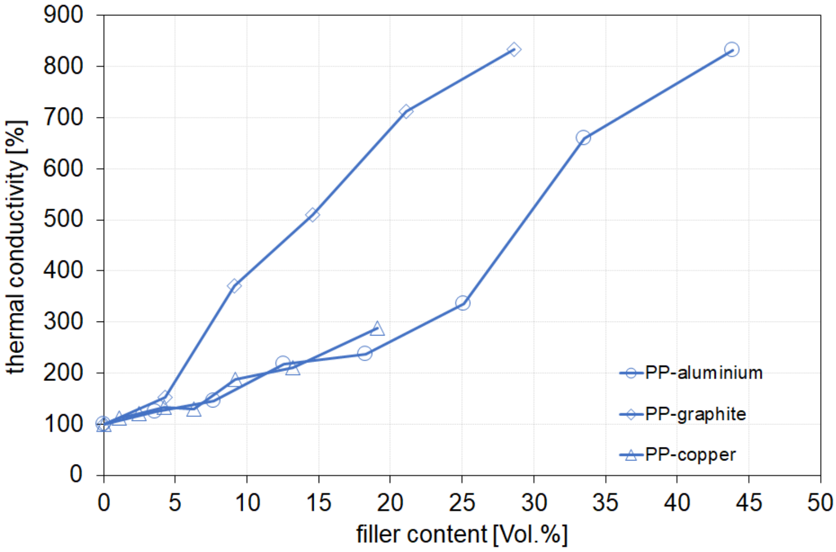

Figure 4: Thermal conductivity vs. filler type and content of PP based composites

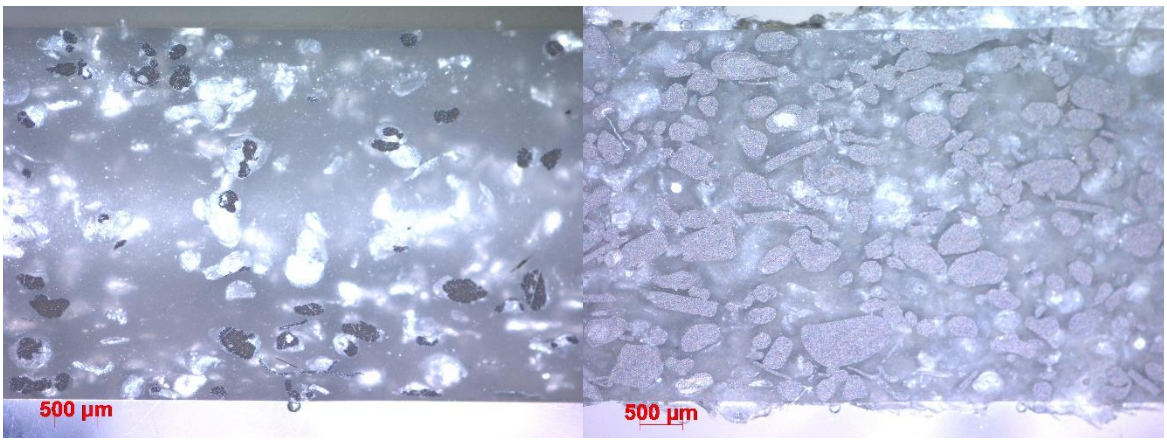

Figure 5: Cross-section of the PP specimens containing 12 Vol.% (left) and 33 Vol.% (right) aluminium; (in these pictures, the aluminium particles from deeper layers reflect light, as the PP is translucent, thus producing the glow-effect)

Looking at the different fillers in the different polymers, as shown in Fig. 6, the general trends found are the same as for PP. There is an initial increase, which gets steeper with increasing filler content, due to the aforementioned particle-particle interactions. Also, graphite performs better at comparable volume fractions due to the higher specific surface compared to the more “spherical” copper and aluminium particles. But also another effect can be seen here, if closer attention is paid to the different graphite composites. The composites with PC and PA yield higher thermal conductivities than the ones with PP. We suspect this being due to the wetting of the graphite by the matrix, which should be better with PC and PA due to their chemical nature (e.g. being able to form hydrogen bonds) in comparison to PP.

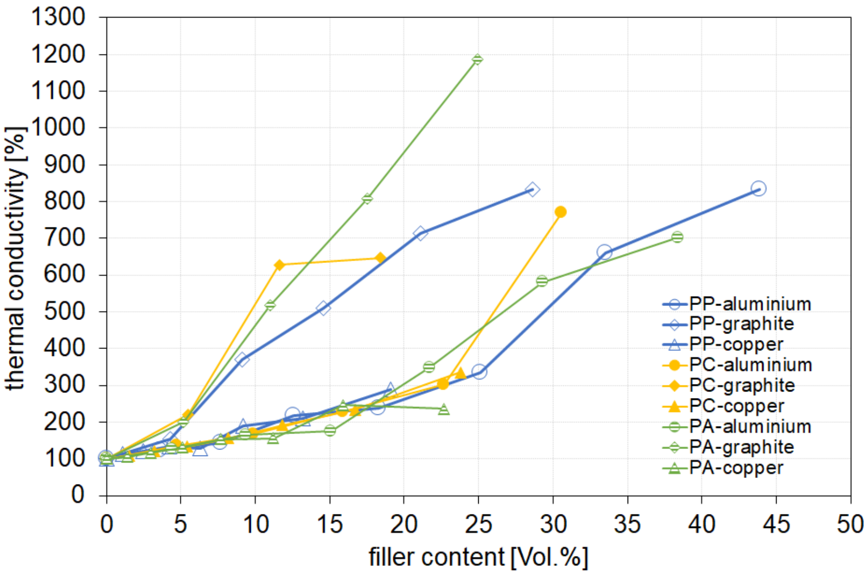

Figure 6: Thermal conductivity vs. filler type and content and polymer matrix in the investigated composites

Conclusion

With the application of the Hot Disk method, we have a tool for characterising the thermal conductivity of different particle filled thermoplastics. The results show that it is possible to increase the thermal conductivity of these systems up to tenfold, depending on the exact materials combination. For example, with graphite at a loading of 20 wt% (which equals approx. 11 Vol.%), PC reads 1.48 W/mK and PA 1.16 W/mK (compared to around 0.23 W/mK for both base polymers), which are values of interest for cooling applications. Also, with these investigations, we were able to identify the main influencing parameters, i.e. that graphite yields better results here as it exhibits preferable particle dimensions, and that the interaction of the polymers containing functional groups is favourable for the interaction of the polymer with the filler.