PHOTO: LANXESS

LED lighting is one of many potential application areas for thermally conductive plastics. **Peter Mapleston** takes a look at some of the additive technologies available to those aiming to develop thermal management solutions

Lights on but the heat is off

Whether it's for E&E applications, automotive, or other branches of industry, the demand for thermally conductive plastics is cranking up as end users begin to appreciate how such materials can score over metals in terms of down-sizing, complex geometries, lightweight construction, improved functional integration, part consolidation, and more cost-efficient production. And aside from replacement opportunities, these new polymer materials may also create totally new markets.

Lighting is one key market and a variety of compounds, mostly based on polyamides and thermoplastic polyesters, have been developed for LED lamp and luminaire applications. According to at least one polymer compound supplier, there has been a particularly sharp rise in demand for thermoplastic materials that meet specific thermal conductivity requirements from the lighting sector and further afield. The reasons for this include the continuing reduction in size and increase in power of electronic devices and assemblies, which results in the generation of increasing amounts of heat that must be dissipated in a controlled manner. In the case of LEDs, for example, effective cooling is essential to prevent declining brightness or lifespan.

At compounding company **Lehmann & Voss**, Customised Polymer Materials Global Product and Marketing Manager Thomas Collet points to a recently developed product, Luvocom 1800-9333/WT. This PET-based compound offers high thermally conductivity – 8 W/mK – but remains electrically insulating, thanks to the use of a new boron nitride (BN) from 3M.

Collet says that to demonstrate the possibilities that can be realized with this and other Lehmann & Voss products, the company worked in cooperation with 3M and also injection moulding company RF Plast and circuit board producer Häusermann in Germany on a project to develop an innovative high performance, highly integrated LED torch. The torch features a fully integrated circuit board, which is over-moulded with the Luvocom compound. As the polymer compound is bright white it also functions as a reflector for the LED light.

The high power LED lamp produces light equivalent to a traditional 40 Watt light bulb. Using a conventional polymer material for the torch body would result in the temperature rising up to 150°C around the LED, Collet says, causing it to overheat. "Thanks to the highly conductive material the temperature around the LED is only 73°C," he says. At the housing, the temperature reaches no more than 40°C. The developers say the high-performance torch is reliable, durable and light, and because of the functional integration, costs are relatively low.

The project used **3M**'s Boron Nitride (BN) Cooling

Main image: LED lighting is a key area of interest for thermally conductive compound producers

Above: Lehmann & Voss collaborated with 3M, RF Plast and Häusermann to develop this LED torch

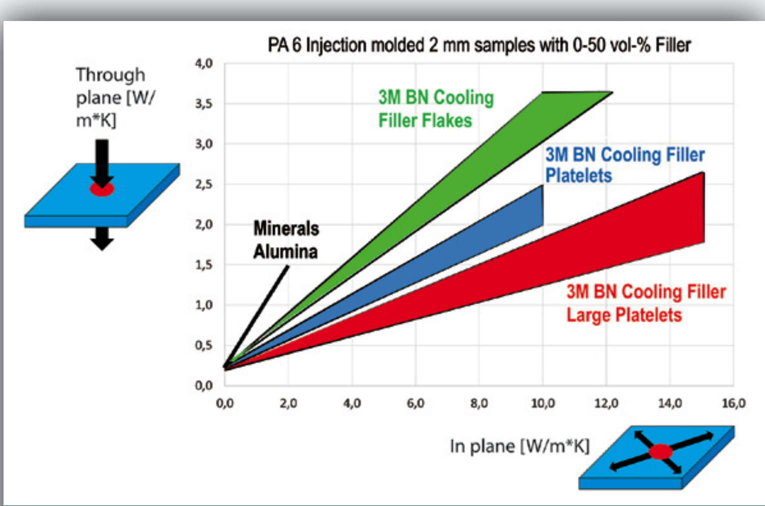


Figure 1: In plane and through plane thermal conductivity data of different 3M boron nitride additives in PA6 moulded plates

Fillers, which the company describes as a "game changer" for functional integration in advanced electronic constructions. "Not only the known excellent thermal conductivity but the balance of properties make it the preferred filler choice for functionally integrated designs as shown by the LED torch demonstrator," says Armin Kayser, Manager for Product and Application Development in 3M's Advanced Materials Division in Kempten, Germany.

Kayser points out that the thermal conductivity of compounds can be adjusted between 1 and 15 W/mK with the addition of between 10 and 50% (by volume) of the same filler product. "This can be basis for a platform concept of compounds addressing the whole spectrum of application needs," he says. For medium performance compounds (containing 20-30% of the BN additive for a conductivity of 3-5 W/mK), secondary additives such as glass fibres, pigments and flame retardants can be added without compromising the processing characteristics of the compound.

The good flow and moulding properties of BN-based compounds allow complex and thin-walled moulds to be filled, Kayser adds. Injection pressure is typically increased by less than 50% compared to unfilled compounds. This is important for several reasons, not least of which is that low injection pressures are necessary for functional integration of printed circuit boards and other electronic components. Kayser further claims that thermally conductive compounds commonly result in high wear of steel moulds, "but this becomes a non-issue when using dry lubricating 3M BN Cooling Fillers."

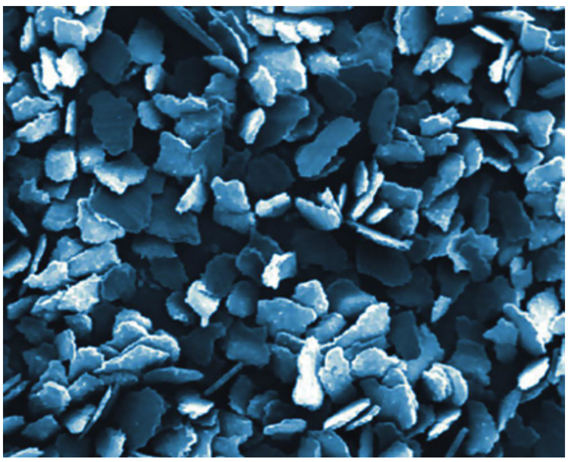
The 3M fillers show an optical reflectivity of over 90% in all visible light bands. On this basis, compounds can be used for highest optical quality reflectors. Meanwhile the platelet structure of these particular additives effectively reduces the thermal expansion of polymer compounds. Expansion can be adjusted to the same level of copper used in printed circuit boards, for example.

3M Boron Nitride Cooling Filler Platelets are suitable for most thermoplastic compound applications requiring excellent heat dissipation properties, Kayser claims. However, for applications requiring high thermal transfer through thin electrical insulating walls 3M has developed a new generation of fillers that achieves up to 4 W/mK in the through-plane direction at 50% loading by volume (Figure 1). "3M BN Cooling Filler Flakes offer a unique combination of high in-plane and through plane conductivity," Kayser says. "At filler loadings of up to 50%, compounding normally becomes challenging with BN products, but not when using 3M BN Cooling Filler Flakes. Due to their larger size (200 microns) and high density, they can easily be compounded at even higher concentrations than 50%."

Saint Gobain also supplies BN additives. The company's Marketing Manager Neelam Kumar reports an increase in awareness in the market for the product in what he says are still niche applications for thermally conductive, electrically isolating (TC, EI) plastics. "As electronics are becoming smaller yet more powerful with every generation, the need for TC and EI plastics for casings, housings and enclosures of these devices is growing tremendously," she says.

The company's CarboTherm PCTP30D grade is designed specifically for use in plastics and performs well in thermoplastic compounding applications, Kumar says. "It flows well in high-volume automated dispensing equipment, providing up to 25% increase in throughput, which has been a challenge for most BN fillers," she claims. "Because of its unique particle size distribution after dispersion in a twin screw compounder, it offers highly optimised thermal paths along the matrix, and therefore higher thermal conductivity along the z-plane."

Silatherm aluminosilicate mineral fillers from **HPF The Mineral Engineers**, a division of the Quartzwerke Group, have been used in serial thermal management



Right: 3M's Boron Nitride Cooling Filler Flakes are said to offer improved thermal performance at thinner wall sections

Table 1: Mechanical and thermal properties of PA6 compounds containing different Silatherm aluminosilicate fillers at 65 wt% loadings

Mechanical properties

Product	Filling [wt.%]	Tensile stress [MPa]	Breaking elongation [%]	E-Modulus [MPa]	Impact resistance [kJ/m²]	Notched impact resistance [kJ/m²]
Silatherm 1360-400 AST	65	94	3,7	10000	42,1	3,1
Silatherm T 1360-400 AST	65	94	4,2	10100	61,5	4,3
Silatherm Advance 1438-800 AST	65	104	6,2	8080	95,2	5,9

Thermal properties

	Filler proportion				Z-direction		X-direction	
Product	Target [wt.%]	*AC [wt.%]	Density [g/cm³]	HDT A [°C]	cp [J/gK]	Thermal conductivity [W/mK]	cp [J/gK]	Thermal conductivity [W/mK]
Silatherm 1360-400 AST	65	64,4	1,99	142	1.08	1,2	0,92	1.3
Silatherm T 1360-400 AST	65	64,1	1,99	140	1.09	1,0	0,69	1.3
Silatherm Advance 1438-800 AST	65	63,7	2,27	119	0.93	1,0	0,87	1.4

*Ash content 750°C; 10 min. (Thermal conductivity of unfilled PA is 0.3 W/mK.) *Source: HPF The Mineral Engineers*

applications for more than one year, according to the company's Market Development Manager Péter Sebö. "Its use grants better properties regarding mechanical stiffness and thermal performance whilst being a perfect electrical insulator," he says.

One of the company's most recent developments is Silatherm Advance, which Sebö describes as "a whole new grade of thermal conductive filler" that provides increased thermal conductivity and improved mechanical properties. The additive, like BN, is naturally white in colour. "Target application markets like EMC, automotive, LED-lightning systems and others are now within reach with this new product," Sebö claims.

Tests comparing the mechanical and thermal performance of Silatherm Advance 1438-800 AST in polyamide 6 against with compounds using the company's existing Silatherm 1360-400 AST and Silatherm T 1360-400 grades show positive results (see Table 1). "Silatherm Advance shows similar thermal conductivities, a much better impact and higher tensile stress," says Sebö. "Higher filler proportions are possible to achieve higher thermal conductivities." For example, at an addition rate of 75% (by weight) Silatherm 1360-400 AST provides a thermal conductivity of 2.0 W/mK in PA6 (the thermal conductivity of unfilled PA is 0.3 W/mK).

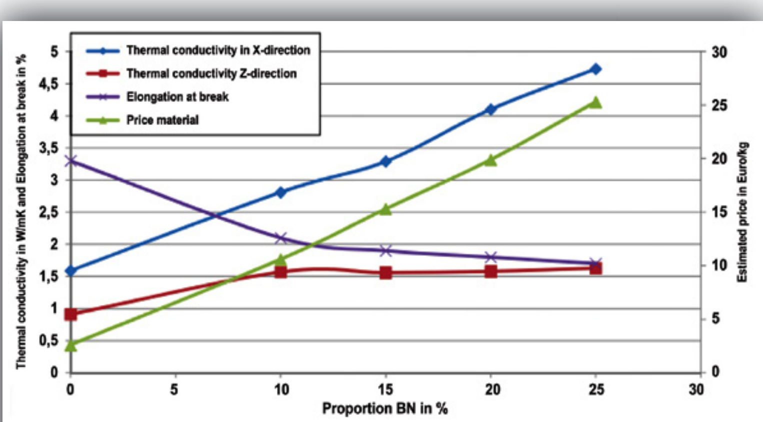


Figure 2: Influence of aluminosilicate and born nitride combination blends on thermal conductivity and compound cost (based on a 45 volume% loading)
Source: HPF The Mineral Engineers

Sebö also highlights the potential for combining Silatherm with BN as a route to obtaining cost-effective solutions for heat sinks and other applications. He says several investigations have been carried out, using similar conditions as in the previous experiments, but with a total concentration of 45% by volume (See Figure 2). A combination of the two fillers enables a thermal conductivity up to 4.7 W/mK to be achieved, together with increased isotropy.

Imerys Graphite & Carbon says last year it observed an increasing interest for graphite-based products for thermally conductive plastics applications around the world. Graphite is the best option if electrical conductivity is tolerated and high thermal conductivity is required in a plastic compound, according to Daniele Bonacchi, Development Scientist, R&D Polymer Applications with the company in Bodio, Switzerland.

The main application Imerys is seeing for thermally conductive compound is, once again, LED heat sinks, especially for automotive applications. "According to the compound producers a number of initial formulations are ready (although there is still space for improvement) but the market demand is still relatively low," Bonacchi says. "Imerys can offer primary synthetic graphite with outstanding through plane thermal conductivity and especially designed primary synthetic or natural graphites for high in-plane thermal conductivity" (see Figure 3).

Bonacchi notes that primary synthetic graphite has the advantage of high purity, making it especially suitable for sensitive materials in which transition metal ions can catalyze polymer degradation. Imerys also offers two grades, C-Therm001 and C-Therm011, that are easy to feed and which he says are able to deliver thermal conductivity at lower loadings than standard graphite.

"Although graphite is already an extremely light additive, for critical applications such as automotive lamps, where weight saving can be of utmost importance, C-Therm can decrease further the compound density," Bonacchi says. He also says that, during the company's participation in the European Union-sponsored four-year NanoMaster Project, which ended last year, Imerys developed a new easy feedable thermally conductive additive called C-Therm301, which provides good thermal conductivity with improved mechanical properties.

The aim of the NanoMaster Project was to develop the knowledge-based processing methods required to up-scale the production of graphene and expanded graphite reinforced thermoplastic masterbatches and compounds and, ultimately, enable its industrial commercialisation in Europe. The work focused on developing processes for large scale rapid production of graphene reinforced plastic intermediate materials for integration into current conventional and additive manufacturing processes.

The project organisers said that while graphene reinforced polymers have been demonstrated at lab scale in both Europe and the USA, and it has been shown that very low loadings of graphene can have a dramatic impact on the mechanical and physical properties of the polymers it is added to, industrial compounding processes have only so far been developed in the US (where Ovation Polymers offers graphene thermoplastic masterbatches and compounds based on graphene from XG Sciences.)

Imerys is also promoting extremely large flake synthetic graphites, such as KS 150-600SP, which behave very differently from large flake natural graphite (Figure 4). "This material forms compounds with very high through-plane thermal conductivity and can be useful for cooling pipe applications or applications in which high through plane thermal conductivity is needed," Bonacchi says. But he does also note that, due to the large particle size, mechanical properties can be reduced.

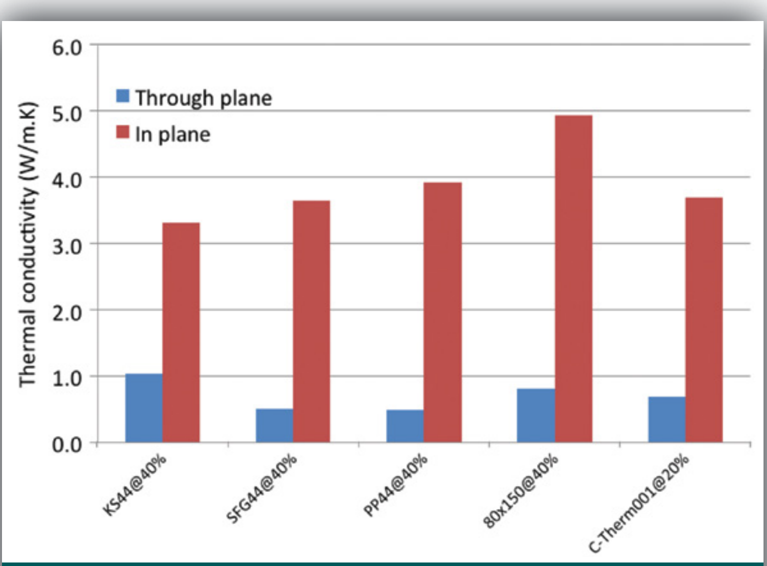


Figure 3: In-plane and through-plane thermal conductivity of injection molded HDPE plaques loaded with different Imerys graphite grades
Source: Imerys

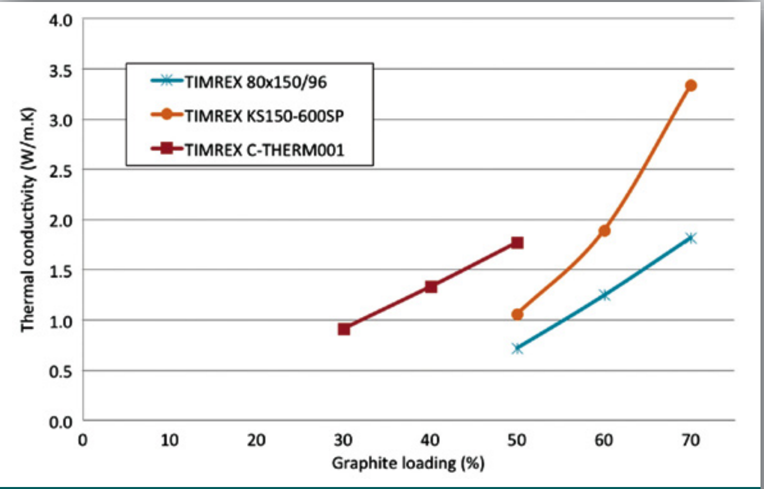


Figure 4: Through-plane thermal conductivity versus loading for compression moulded PP homopolyer plaques containing different graphite grades
Source: Imerys

Improved isotropy

Among the major producers of thermally conductive compounds, **Lanxess** says the Durethan reinforced polyamide 6 compounds that the company introduced at K 2013 conduct heat efficiently while at the same time being electrically insulating. Their thermal conductivity lies between 1.0 and 2.5 W/mK. The first representatives of the line are two easy-flow types, Durethan BTC65 H3.0 EF and BTC75 H3.0 EF. Their thermal conductivity is based on reinforcement with 65 and 75% by weight of a mineral, which the company does not

Figure 5: Typical characteristics of additives for thermally conductive polymer compounds

	Filler	Structure	Geometry	λ [W/m*K]	Density [g/cm³]	Hardness (Mohs)	Color	Costs [€/kg]
Electrically isolating	Aluminosilicate	Al2[O|SiO4]	irregular	14	3,5	5,5	grey	2 - 4
	Magnesium oxide	MgO	irregular	30	3,5	6	white	4 – 8
	Alumina	Al2O3	irregular	30	3,95	9	grey	2 - 4
	Boron nitride	BN	platelet	15 / 400	2,1	2	white	50 – 70
Electrically conductive	Silicium carbide	SiC	irregular	60 – 160	3,1 – 3,3	9,6	grey	40 – 70
	Graphite	C_n	platelet	150	2,1	1	black	2 – 20
	Carbon fiber	C_n	fiber	390 – 750	1,8	2	black	20 - 40
⚠	Copper	Cu	various	398	8,9	2,5	red	6 - 15

Source: Ensinger

Figure 6: Processing challenges of thermally conductive compounds

Feature	Process technology
High filler content	• feeding technology • pelletizing technology
High thermal conductivity	• control of process temperature
Hardness/abrasion	• screw design • wear protection
Shear-sensitive fillers	• screw configuration
Brittleness	• pelletizing technology

Source: Ensinger

identify. "Both materials display an ideal balance between high thermal conductivity, impressive mechanical properties and good processing behaviour," the company says.

Thermal conductivity of these compounds is close to being isotropic, Lanxess says. Despite the high mineral content, both compounds are also said to be easy to process using injection moulding.

A more recent development from the company is another highly filled polyamide 6 compound currently called Durethan TP723-620 (TP stands for Trial Product). This has anisotropic thermal conductivity: approximately 2.5 W/mK in the direction of flow and approximately 1.4 W/mK perpendicular to it. This compound also offers UL94 V-0 flame retardance with a wall thickness of 0.75 mm, together with enhanced reflectivity of around 85%.

Conductive yarns

Compounding company **Grafe Polymer Technik** is also making moves in the area of thermally conductive grades but is beating its own path. Project manager Carlos Caro says: "As a producer of electrically conductive thermoplastic compounds we have been assessing the market in terms of further effects and useful applications. The topic of thermal conductivity has been one of them. Our first activities referred to the increase of thermal conductivity in HDPE for pipes applications.

"In 2011 we analysed some benchmarks and came to the special boron nitride products of ESK Ceramics (now 3M). However, due to the fact that many companies like SABIC, Bayer, Schulman, Barlog, Albis, Ensinger and others have been focusing successfully on materials for injection moulding and extrusion, we wanted to take a different approach by inducing a thermally conductive effect on synthetic spinning yarns (PA, PP or PET)."

Caro says this was done successfully in 2013, with Grafe able to produce its own spinning yarn made of PP with a BN content of 25%. "The special preparation of this BN material brings positive aspects for spinning yarns like free flowing behavior, no-dust, low hardness (Mohs 1) and low heat-up during extrusion at higher loadings. The cooling periods are also very short. Most important also is the chance of colouring the materials," he says. "However, the main open issue lies in the fact that the measuring techniques are only focused on parts made via injection moulding or sheet extrusion. Up until now it has not been possible to measure the exact level of thermal conductivity on our PP yarns."

Caro says external research indicates it should be possible to reach thermal conductivity values over 5 W/mK at a BN level below 30%. "Additionally, the possibility of production and use of thermally conductive yarns has not been assessed in full by the yarn and smart textiles producers due to the complicated supply chain with many partners and companies in between," he says.

Several suppliers of thermally conducting additives, compounds and finished parts presented their latest

Right: Desalination plant heat exchanger tubes manufactured in a PP-graphite compound by Technoform Kunststoff-profile

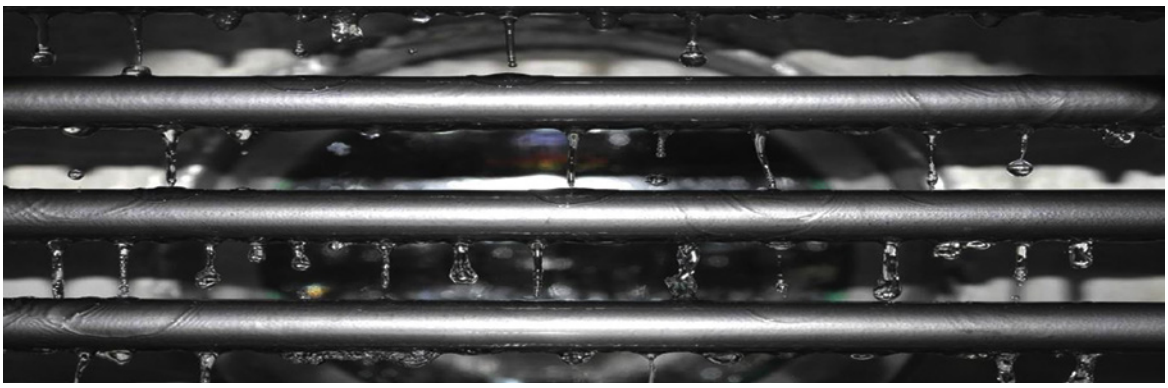
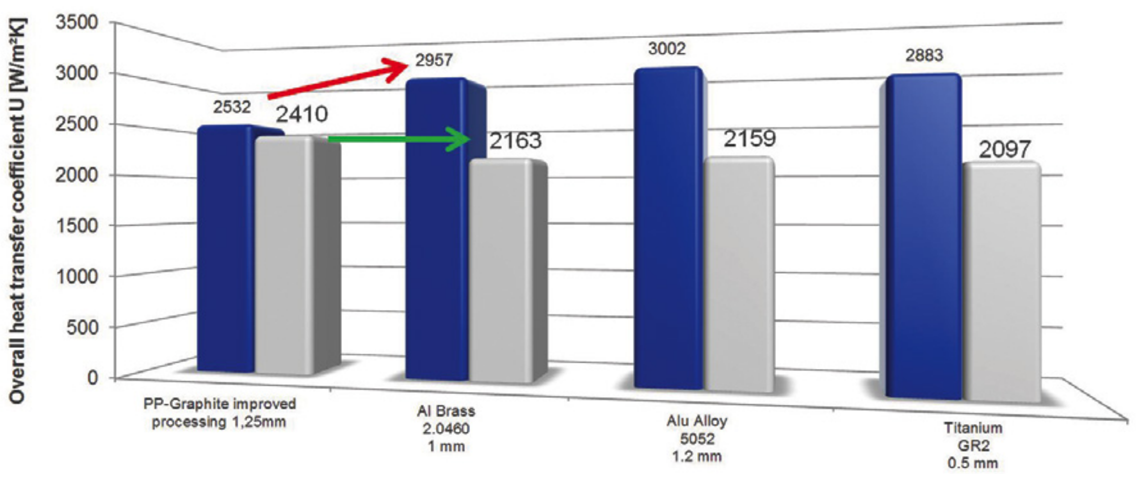


Figure 7: Thermal properties of PP-graphite desalination plant heat exchanger tubes compared with metal types as manufactured and after 1,000h of fouling/scaling exposure

Source: Technoform Kunststoffprofile



developments at the first Conducting Plastics conference held by *Injection World* publisher AMI last year. Among them were 3M and HPF, compound producers Ensinger, Lati and SABIC, and Technoform Kunststoffprofile, which produces special types of tubing.

Ensinger Account Manager Jürgen Fraer spoke about opportunities, challenges and applications for thermally conductive compounds. Depending on the system conditions (convection, heat transfer coefficient, power loss) the moderate thermally conductivity of thermally conductive compounds are sufficient for their use as heat management materials, he noted. And while high filler loadings influence the characteristics profile and the processing behaviour, not infrequently in a negative way, thermally he said conductive plastics can also be further modified and functionalised to meet end-use requirements.

Lati's Special Compounds Marketing Manager Luca Posca provided practical advice on materials selection, part design and moulding techniques when using thermally conductive plastics. He highlighted how, especially in parts with thin walls and compounds containing conductive flakes, conductivity values vary considerably according to the axis they are measured along. "All parts requiring good transversal thermal conductivity may gain efficiency introducing thicker walls where necessary," he pointed out.

Size and aspect ratio of particles influences thermal conductivity. "Large flakes featuring pronounced aspect ratios will provide much better conductivity even in low percentages." Within the NanoMaster Project, Lati technicians have carried out many experiments. Dispersion and exfoliation of a graphene-like nanographite was studied and the thermal conductivity of the resulting compound has been measured. "High aspect ratio enhances conductivity even at low filler content," Posca said. "Preservation of particles integrity and aspect ratio is fundamental, so excessive shear stresses ought to be avoided as much as possible."

German processor **Technoform Kunststoffprofile** is developing applications for thermally conductive plastics in heat exchangers. In a discussion about seawater desalination plants, R&D Engineer Sebastian Ossadnik said the company had developed tubes made from polypropylene compounds containing graphite. He said the company had to develop special processing techniques to achieve optimum results. Even so, the "as extruded" thermal conductivity of its plastics tubes was lower than that for metal. However, further application testing showed thermal conductivity after ageing of the PP-graphite tubes to be better than some metallic alternatives due to the higher resistance to scaling.

Conductive Plastics 2016

AMI will run its first Conductive Plastics conference in North America later this year. Focused on the formulation and processing of both thermally conductive and electrically conductive plastics, the event will take place in Philadelphia, PA, USA, on 27-28 September. To find out more about attending or exhibiting at the event, which is sponsored by Premix, contact senior conference coordinator Kelly Cressman.
Tel: +1 610 478 0800; Email: **kc@amiplastics-na.com**.
Or visit the conference website **http://bit.ly/CPUS16**

Click on the links for more information:

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