Industry Developments:

Thermally Conductive Polymers

Polymer materials are often used as heat insulators, but they are also formulated to be thermally conductive. Heat conducting polymers have been in development for years. But, improvements are needed before commercial-grade materials equal the thermal performance of metals and ceramics.

The thermal conductivity of polymers is typically 0.1-0.3 W/mK. Adding thermal fillers to the compounds can increase thermal performance by modest levels. For some polymers, thermal conductivity is dramatically higher, but these materials are typically not available at market competitive prices.

Still, polymers have several desirable features for use in providing heat transfer. Compared with metal heat conductors, polymers are easier to shape, lighter in weight, water resistant and offer some compressibility.

In a recent Omnexus survey of plastic and elastomer industry experts, more than 92% expect moderate to significant near term growth in thermally conductive polymers. The responders thought significant growth would be driven nearly equally by the goals of weight savings and system cost reduction. [1]

Lighting Applications

Among the current uses for thermally conductive polymers are lighting applications. Plastic reflectors, situated where the temperature is the highest when the light is turned on, can be designed with a heat-dissipating polymer.

Figure 1. A Demo from Cool Polymers Shows the Performance of a Thermally Conductive Heat Sink vs. a Conventional Plastic Sink [3]

More than 80 million LED lighting systems use CoolPoly thermally conductive plastics, manufactured by Cool Polymers, Inc. According to the company, this equals an annual energy savings for users up to $115 million.

Cool Polymers is the original manufacturer of thermally conductive thermoplastics for injection molding. Their engineers realized that thermally conductive plastics were a flexible and low cost solution for managing excess heat from the tiny LED chips. With a proven and in-demand product line, Cool Polymers has opened new facilities in Rhode Island. [4]

Automotive Applications

Thermally conductive polymers have also been studied for automotive applications, where weight saving is critical and where they can potentially replace metal parts. PolyOne Corporation presented "Metal Replacement with Specialty Thermoplastic Solutions in Heat-Sensitive Automotive Applications" at the 2013 SPE Eurotec Conference. Their presentation covered the use, value and specific economic benefits of conductive thermoplastics in heat-sensitive automotive applications, including metal replacement in automotive LED lighting.

Another thermoplastics compounder, RTP Company, has introduced thermally conductive compounds for replacing metal components in automotive heating and cooling systems. The new materials are specially formulated to increase the thermal management design options available to automotive industry engineers as they strive to reduce vehicle weight to improve fuel efficiency.

According to RTP Co., thermally conductive compounds offer many benefits over aluminum or stainless steel for vehicles. Advantages that plastics offer over metal materials include: the ability to provide electrical isolation, reduction in part weight by up to 50%, lower manufacturing costs and simplified production using efficient injection molding processing, and longer system lifecycles by eliminating corrosion. [5]

Automobile systems for redesign using thermally conductive compounds include both air-cooled and liquid-cooled systems for batteries, emissions control, lighting modules, and electric vehicle thermal management. Thermal conductivity characteristics can be incorporated into a variety of resin systems, among which are polypropylene, polyethylene, polybutylene, terephthalate, nylons, polyphenylene sulfide and polyphthalamide.

Per RTP, in-plane thermal conductivity values up to 35 W/mK can be achieved using a variety of additives. The thermoplastics can be either electrically insulating or electrically conductive.

Thermally Conductive Polymer Product Lines

In addition to heat sinks and heat pipes, demand for thermally conductive thermoplastics for housings has risen sharply in recent years. Lanxess Corporation is developing a new line of polyamide products called Durethan TC (thermally conductive). The first representatives of this line are two easy-flow polyamide 6 variations: Durethan BTC65 H3.0 EF and BTC75 H3.0 EF. Their high thermal conductivity is based on reinforcement with 65 and 75 percent of a special mineral. [6]

According to the Lanxess, both materials display a very good balance between high thermal conductivity, outstanding mechanical properties and good processing behavior. They have been successfully tested and approved by two international automotive suppliers and are poised for use in full-scale production.

The thermal conductivity of the two Durethan materials was determined by the UL Nanoflash test method, a contact-free determination of the thermal diffusivity of materials [7]. In the case of the polyamide with 65 percent mineral reinforcement, this value is 1.0 W/mK, or three times higher than that of Durethan BKV 30 H2.0, a Lanxess polyamide already used in automotive engineering. The material has a 75 percent mineral

Figure 2. Cool Polymer Heat Sink and Heat Pipe Products Made from Its CoolPoly Thermally Conductive Plastic Materials [3]

content tested at 1.5 W/mK, meaning it is even 4.7 times more conductive. The two materials conduct heat as efficiently as polyamides containing boron nitride or aluminum oxide as a thermally conductive filler.

The new injection-moldable materials also have the potential to replace pure metals. Compared to die-cast aluminum, housings have been fabricated from the two thermoplastics much more cost-effectively, particularly in the case of high production volumes, and they yield more lightweight components. They also demonstrate high tensile strength and impact resistance, which are essential for packaging materials.

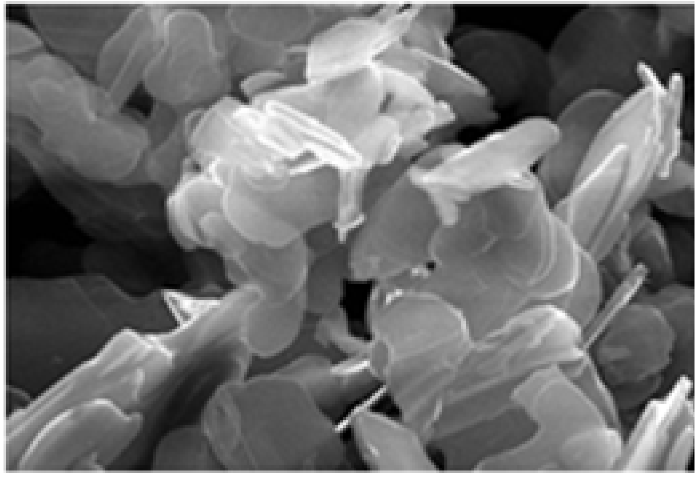

Figure 3. CarboTherm Hexagonal Boron Nitride (hBN) Products from Saint-Gobain Add Thermal Conductivity to Thermoplastic Compounds [8]

New and Improved Filler Materials

Saint-Gobain's Boron Nitride group has developed CarboTherm hexagonal boron nitride (hBN) products for adding thermal conductivity to thermoplastic compounds. They can be used to create products that dissipate heat while retaining electrical insulation. [8]

According to the company, ceramic fillers are the only option for adding thermal conductivity to plastics while retaining electrical insulation properties. hBN is the ceramic filler that provides the lowest density and the lowest coefficient of friction.

Manufactured from the high-temperature synthesis of boron and nitrogen pre-cursors, hBN is a white additive available in large crystal sizes for maximum thermal conductivity. Four different grades are available for plastics applications.

PCTF5, PCTP16 and PCTP30 are single-crystal platelet powders suitable for medium volume, semi-automated loading systems. PCTP30D is a free-flowing agglomerated powder suitable for high-volume, automated loading systems. The apparent density of the grades is 2.2 gm/cc, their coefficient of friction is less than 0.3 and their thermal conductivity is 30-130 W/mK.

Target applications include custom-molded heat sinks for circuit boards, tubing for heat exchangers in appliances, insulation for high-speed rotating machine components, enclosures for LED bulbs, telecommunication device components and automotive under-the-hood and electronic components.

Nanoparticle Filled Polymers

Carbodeon, a supplier of superhard materials such as nano-diamonds and graphitic carbon nitride, has released a thermally conductive nanodiamond filler it claims increases the conductivity of thermally conductive polymers by 25 percent. [9]

According to the company, the increase in thermal conductivity is achieved without affecting the electrical insulation or other mechanical properties of the material, making it an ideal choice for a wide range of electronics and LED applications. The formulation of the new material is based on PA66 (polyamide 66, an engineering thermoplastic), with 45 percent by weight boron nitride thermal filler; however, the boron nitride filler was replaced with a new mixed filler comprised of 44.9 percent by weight boron nitride and 0.1 percent by weight uDiamond NanoDiamond material.

The performance improvements achieved by this filler are derived from the extremely high thermal conductivity of diamond, at around 2000 W/mK, states Carbodeon. The key development was to tune the surface chemistry of the diamond particles and mixing process to develop a nano-composite in which the diamond is very well interfaced to the polymer molecules.

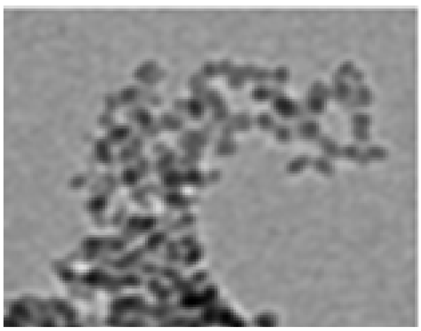

Figure 4. Nanodiamond Technology from Carbodeon Produces High Purity uDiamond Products with Typical Size in the 4-6nm Range [9]

Research Continues

A research team at MIT developed a new process that causes the polymer to remain an electrical insulator but conduct heat very efficiently in just one direction, unlike metals, which conduct equally well in all directions. The key to the transformation was getting all the polymer molecules to line up the same way, rather than forming a chaotic tangled mass, as they normally do. The team did that by slowly drawing a polyethylene fiber out of a solution, using the finely controllable cantilever of an atomic force microscope, which they also used to measure the properties of the resulting fiber. This fiber was about 300 times more thermally conductive than normal polyethylene along the direction of the individual fiber, according to the MIT team. The high thermal conductivity could make such fibers useful for dissipating heat in many applications where metals are now used, such as solar hot water collectors, heat exchangers and electronics.

According to the MIT researchers, most attempts to create polymers with improved thermal conductivity have focused on adding in other materials, such as carbon nanotubes, but these have achieved only modest increases in conductivity because the interfaces between the two kinds of material tend to add thermal resistance. [10]

The NanoEngineering Group at MIT fabricated ultra-high molecular weight polyethylene (UHMWPE) nanofibers with thermal conductivity values as high as ~ 104 W/mK, which is larger than the conductivities of about half of the pure metals. Their high thermal conductivity is attributed to the molecular orientation of polymer chains during ultra-drawing, which improves the fiber quality toward an ideal single-crystal fiber.

The Group also provided a theoretical estimate for the thermal conductivity of a polyethylene bulk single crystal based on molecular dynamic simulations. Their estimated value of 180 ± 65 W/mK indicates that it may be possible to improve the thermal conductivity of polyethylene to a range where it is competitive with aluminum (235 W/mK). [11]

Thermally Conductive Films

BTECHCORP has patented a process for aligning fine (3-15u diameter) continuous fibers through the thickness (Z axis) of a polymer matrix. Up to 20 million fibers can fill a square inch. The unique, highly thermally conductive graphite fibers (1900 W/mK) are used to create a Z-axis bulk thermal conductivity of 750 W/mK (at 40% fiber volume).

HM-2 thermally conductive adhesive film is currently being used or evaluated for a variety of thermal interface material applications, including die attach, LED assembly, heat pipe attachment and heat sink attachment. Continued development has demonstrated lower total thermal resistance. [12]

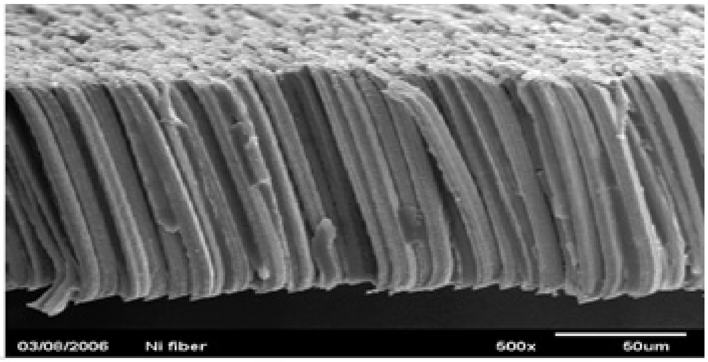

Figure 5. Fibers with 40% Nickel Graphite Content Provide a Z-Axis Thermal Conductivity of 750 W/mK [12]

A Promising Future

Thermally conductive plastics are now used for LEDs in automotive, transportation, architectural, medical, aerospace and general illumination. Further improvements in performance and affordability will boost their demand.

Table 1, below, compares the reported thermal conductivities of materials mentioned in this article. Other thermally conductive polymers are available or in development within the global polymer industry.

Thermal Conductivity of Select Polymers	
Material	**W/mK**
Basic Polymers	0.1-0.3
Durethan (Lanxess)	1.0-1.5
RTP 200 (RTP)	1.0-32.0
CarboTherm PCTF (Saint-Gobain)	30-130
UHMWPE (MIT Study)	104
Single Crystal Fiber Filled (MIT Study)	235 (theoretical)
Graphite Fiber-Filled Film (BTECH)	750

Table 1. Thermal Performance of Polymer Materials Featured in this Article

"We're seeing a consistent movement towards plastic thermal solutions" states Jessica Weimar, Operations Manager at Cool Polymers. "Thermally conductive plastics provide light weight and design flexible heat sinks and housings that can be injection molded on the same equipment used to manufacture LED optics. This is a tremendous benefit to the integrated manufacturing concept, enabling manufacturers to reduce total cost and eliminate margin stack-up." [3]

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