Tackling the thermal challenge

From smart devices to electric vehicles, opportunities for polymer-based thermal management solutions are growing fast. Peter Mapleston finds out more

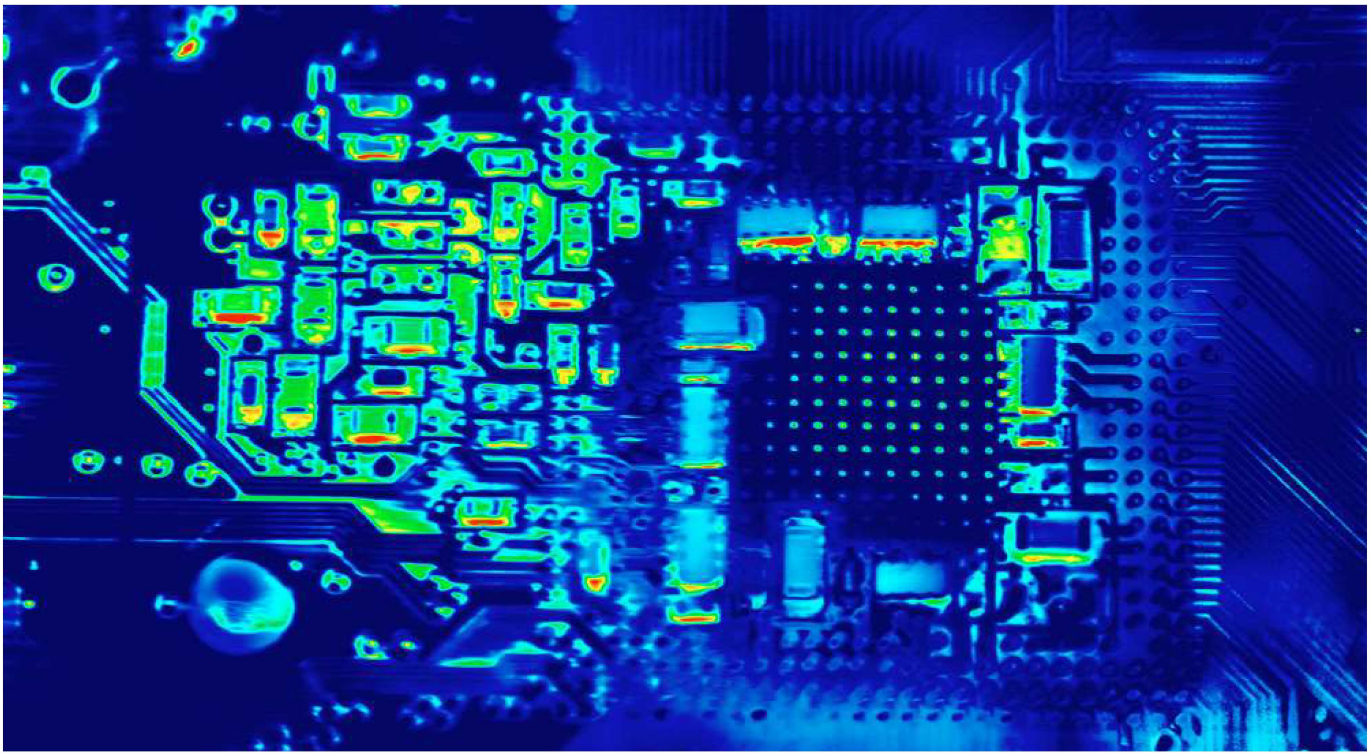


IMAGE: SHUTTERSTOCK

In a market driven by mega trends such as transport electrification, miniaturisation, metal replacement and light-weighting, thermal management increasingly calls for high performance solutions. The low thermal conductivity of thermoplastics historically restricted their use in heat dissipation applications. However, additive and compound developers are rising to the challenge by employing thermally conductive mineral fillers to create polymer compounds that remove excess heat and help keep the end application within its ideal operating temperature range.

As sales of electric vehicles (EVs) grow worldwide, for example, there is an increasing need for materials that can support the new technologies they run on. The lifespan of a battery pack can be prolonged if its temperature is kept at a constant and moderate level. Heat produced in the charge-discharge-cycle can be effectively transported away from the system using thermally conductive battery parts such as gap fillers, pads and structural parts. These are often highly loaded with mineral fillers.

Thermally conductive plastics cannot yet be considered mainstream, but opportunities are there to be realised for compounders. "Thermally conductive plastics remain very niche products," says Christine Van Bellingen, Business Development Manager, Conductive Compounds, at Wittenburg Group's **Witcom Engineering Plastics**. "There are barriers to a widespread use which are more price than technically-related when only a minor improvement is necessary over simple plastics. It is the role of the compounder to wisely select the plastics and additives that will offer the best compromise."

Van Bellingen says that Witcom has the products and the ability to meet many of the emerging requirements but adds that partnerships are necessary to deliver the innovation required. "The minor space available and high weight of EV cars will push for new plastics developments involving thermally conductive or EMI shielded thermoplastic compounds, for ECU housings or battery cooling for instance," she says.

Main image: With 'smart' technology finding its way into ever more consumer and industrial devices demand for plastics that can help to manage heat is growing

Nabaltec says it is supporting the growing demand for thermally conductive and electrically insulating materials with new products that allow for very high filling levels while still providing good processability and good mechanical properties in the final compound. These include its Apyral HC (ATH) and Nabalox HC (Al_2O_3) series. All grades from both series are available from the company's plant in Germany, while the Apyral HC series products are also produced at Nabaltec's newest plant in Chattanooga, TN, US, which specialises in production of ground and viscosity-optimised as well as surface treated ATH grades.

Data from Nabaltec (Figure 1) shows how different surface treatments on a fine precipitated Apyral 40CD and Apyral HC 500 affect thermal conductivity (TC) in a filled TPU. To achieve a TC requirement of around 1 W/m·K, a filling level of 60 wt% can be seen to be sufficient. In this case Apyral 40CD with coating B is the recommended option as it gives the best mechanical properties. Where a higher TC is required, the filling level needs to be increased. To reach 1.4 W/m·K, for example, a filler loading of 70 wt% is necessary and that requires the use of a product that is optimised for TC applications. Data in Figure 2 shows that Apyral HC 500 with coating A gives the best all round result of good TC, acceptable mechanical properties, and high flame retardancy (UL94 V-0 at 1.6 mm).

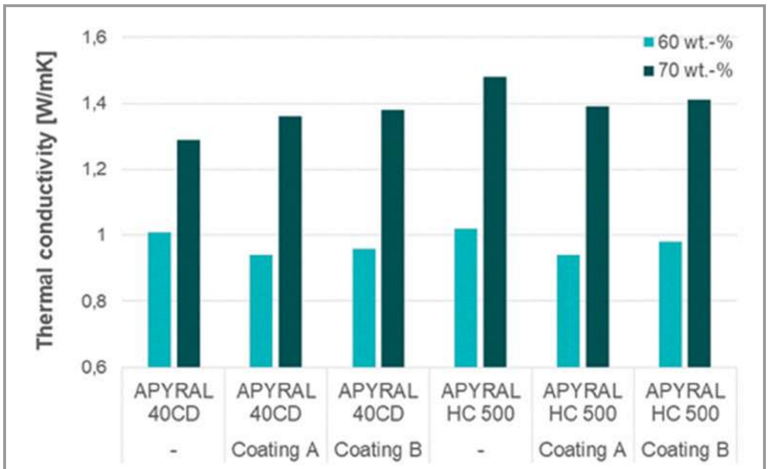


Figure 1: Thermal conductivity of TPU filled with 60 wt% and 70 wt% Apyral grades with different surface treatments
Source: Nabaltec

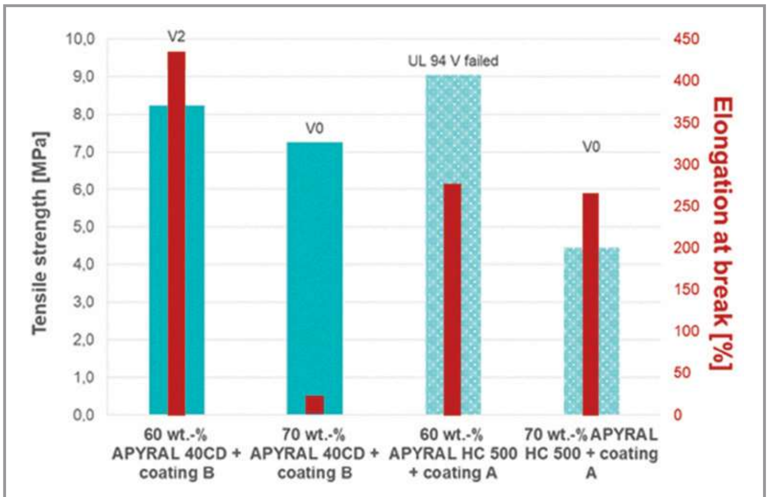


Figure 2: Mechanical properties of TPU compound filled with 60 wt% and 70 wt% Apyral showing effect on flame retardance (UL 94 V test at 1.6 mm)
Source: Nabaltec

Surface effects

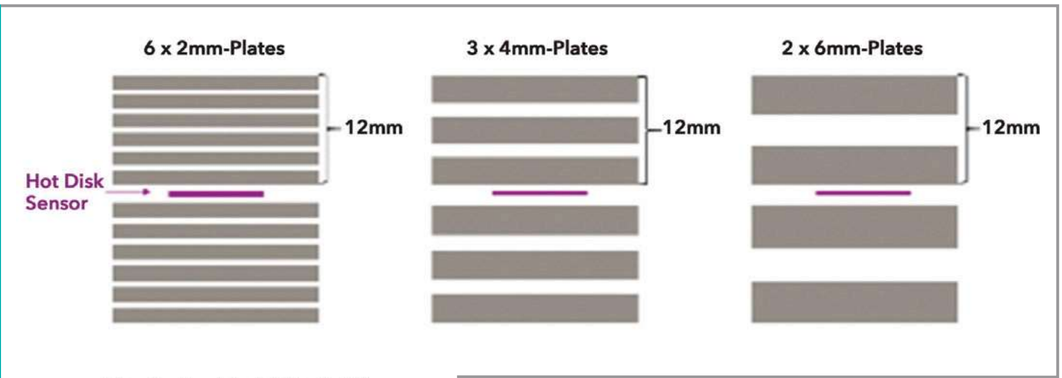
The important role of surface treatments in thermal conductivity of thermoplastic compounds is emphasised by Ido Offenbach, Americas Segments Manager, Specialty Additives at **Evonik**. "Evonik organo-modified siloxane (OMS) surface treatment chemistry have proved to be essential to improve thermal conductivity in different markets and applications such as automotive, electronics, and appliances," he says.

Producers of aluminosilicate, aluminium oxide, and hydroxides of aluminium and other metals often use Evonik OMS surface treatment to increase the level of the filler loading in thermoplastic compounds without compromising mechanical properties or negatively impacting mould filling during injection, Offenbach says. Tegopren 6875 and Tegopren 6879 are two typical examples from the Evonik OMS product line.

"We observed that the thermal conductivity value [W/m·K] of the filler that is added to the thermoplastic compounds is not enough for achieving the target value. Companies must also consider the part configuration (geometry), part thickness (especially if the part contains different thicknesses), and moulding conditions. Therefore, at Evonik we are using a quick screening method to evaluate the thermal conductivity behaviour of thermoplastic compounds via hot plate," Offenbach says.

"We mould plaques with thicknesses of 2mm, 4mm, and 6mm and assemble them to achieve specimens 12mm thick. By doing that we can eliminate variable conditions that influence the thermal conductivity value. For example, a specimen that was made with 2mm plaques of PA containing conductive black filler may show thermal conductivity of 1.46 [W/m·K] via hot plate, while a specimen that was made with 6mm plaques has a value of 2.34 [W/m·K]. The difference is due to air content between the plaques, despite the high pressure applied to bring the stacked samples together," he explains.

"We also found that applying conductive pastes



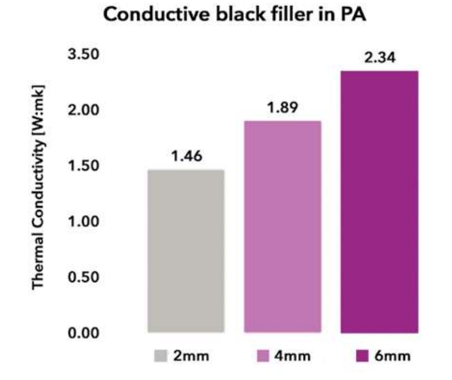


Figure 3: Thermal conductivity of carbon black filled PA measured using hot plate method on stacks comprised of samples of different thicknesses. The top image shows the Evonik screening method for evaluating thermal conductivity behaviour using plaques with thickness of 2mm, 4mm and 6mm together to achieve a total thickness in the specimen of 12 mm. The lower image shows thermal conductivity values of 12mm specimens in PA containing conductive black filler that were assembled from 2mm, 4mm and 6mm plaques

Source: Evonik

between the plaques does not necessarily help. Therefore, for hot disk measurement a high thickness specimen is needed to avoid incorrect reading." Evonik uses laser flash and hot plate methods for measuring thermal conductivity of compounds that contain anisotropic additives.

Evonik also offers solid OMS additives that can be applied in-situ with the fillers during compounding. These include Tegomer H-Si 6441 P, Tegomer P 121, and the newly developed Tegomer H-Si 6444 P. These additives allow loading levels of fillers to be increased without compromising the mechanical properties of the polymer and also improve surface quality and appearance. A further advantage of the OMS chemistry is in improving flame retardance in compounds.

In the matrix

Huber Engineered Materials commercialised its first products for thermally conductive plastics compounds several years ago. It says that while products in its portfolio, such as aluminium hydroxide (ATH), magnesium hydroxide (MDH) and alumina, all provide good intrinsic thermal conductivities, it has focused its development efforts on further improving the interplay between mineral particles and the polymer matrix. Particle morphology and packing optimisation, along with state-of-the-art surface modification techniques, has resulted in the development of a complete portfolio of thermal management additives under the TM designation.

The company recently supplemented its Martoxid TM series with the introduction of the Martinal TM and Magnifin TM series. It says the new products close the gap between performance and safety, suggesting a solution for thermally conductive plastics that fulfils the most demanding flame-retardance requirements.

For EVs, all three ranges offer solutions for thermally conductive gap fillers and pads, especially for silicones, epoxies, PUs and acrylates, but also for polymer applications. "Martoxid TM and Magnifin TM products not only enhance the thermal conductivity (up to 3 W/m·K) of engineering thermoplastics (for example PA6, PA6,6 and PBT) found in the battery housing, but also provide the highest classifications in flame tests (such as UL-94), even for smallest wall thicknesses," the company says.

Boratherm SG (ATH) and Boratherm SA (spherical alumina) from **Sibelco** have been specially developed to improve heat dissipation properties in plastics. The materials are thermally conductive and electrically insulative, while particle morphol-

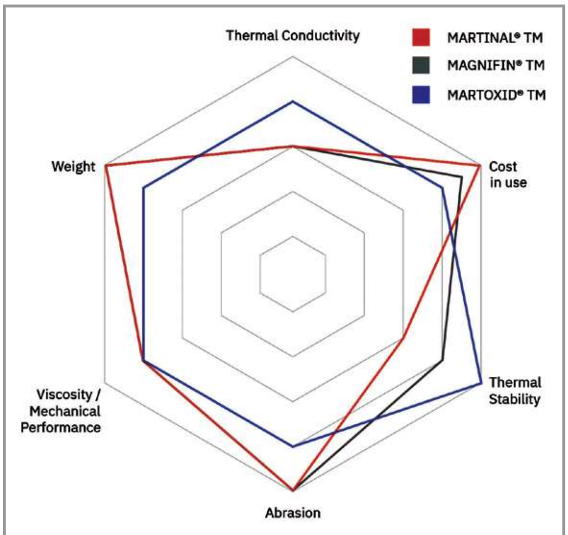
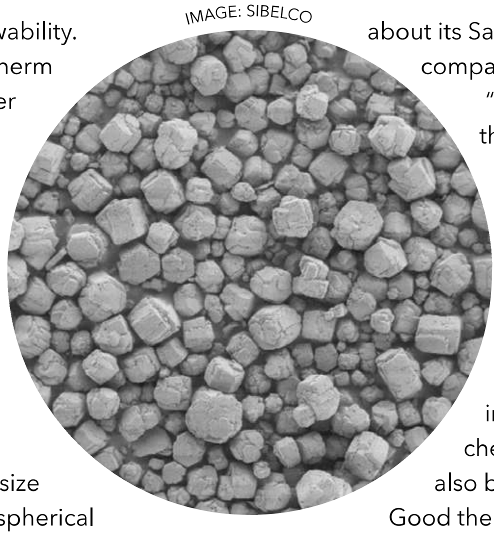


Figure 4: Mineral additives from Huber offer different property balance in finished compounds, including enhanced thermal conductivity

Source: Huber Materials

IMAGE: SIBELCO



Right: Sibelco developed its Boratherm ATH grades to improve thermal dissipation in polymers

ogy is said to ensure good flowability.

According to Sibelco, Boratherm SG is specially designed to offer an ultra-low surface area and large particle sizes, making it well suited for formulations needing good flowability. Boratherm SG-E is a demagnetised ATH option intended for applications with higher demands in terms of electrical insulation.

Boratherm SA is a spherical alumina with a narrow particle size distribution. "Almost perfectly spherical particles enable optimal packing, material flow and heat transfer," says the supplier. Combined with a low specific surface area, Boratherm SA's particle sphericity also allows for good flowability of the formulated material.

Soft solutions

Venator Corporation says it is seeing a significant growth in interest in its Sachtolith HDS for polymer based thermal management solutions. Sachtolith HDS is a soft, white zinc sulphide that can improve the thermal management capabilities of polymer systems without adding electrical conductivity. "Growth in consumer electronics, the popularity of LED lighting systems and the need for batteries with better charging power have resulted in a steady increase in demand for additives that can improve the performance of polymers for some time. However, in the last eighteen months, demand in this area has surged. Since the start of 2020, Venator has seen a sharp rise in enquiries about its Sachtolith HDS additive," the company says.

"The inclusion of additives with thermo conductive properties - such as Sachtolith HDS - can make a decisive contribution to the formulation and thermal performance of polyamide, polycarbonate or polyester compounds. Thermal conductivity is influenced not only by the chemistry of the filler itself, but also by its particle size and shape. Good thermal conductivity requires contact between thermally conductive particles. In addition, the degree of filling required, and the corresponding mechanical stability of the additive can have an impact on thermal performance."

Venator says Sachtolith HDS has a fine and narrow particle size distribution that can enable increased thermal conductivity with optimised mechanical properties. The almost spherical structure of the individual particles reduces the anisotropy effects of thermal conductivity, so enlarging the working window in the production of components. Thermal conductivity of around 1.2 W/m·K can be achieved in polymer compounds, a value that lies within the target range of applications such as LED lighting systems.

"The use of Sachtolith HDS additive enables formulators to retain all the good manufacturing and mechanical properties of glass fibre reinforced compounds and makes the addition of a separate white pigment obsolete," the company says. "In addition, the zinc sulphide surface of the pigment immobilises any migration of, for example, copper ion, meaning service life and temperature stability is enhanced accordingly."

Imerys Graphite & Carbon says its Timrex natural and synthetic graphites and specialty high aspect ratio Timrex C-Therm grades are able to confer high levels of thermal conductivity to polymers. The company says that targets above 20 W/m·K in-plane and 4 W/m·K through-plane can be achieved using the additives while maintaining good processability of the final compound. "In most resin systems, 20% C-Therm loading is sufficient to reach 1W/m·K through-plane thermal conductivity," says Anna Ellett, Imerys Graphite & Carbon Field Application Engineer Polymers.

Imerys Graphite & Carbon supplies graphite solutions with a wide range of morphology and particle size distribution, which enables the fine-tuning of compound properties. This applies

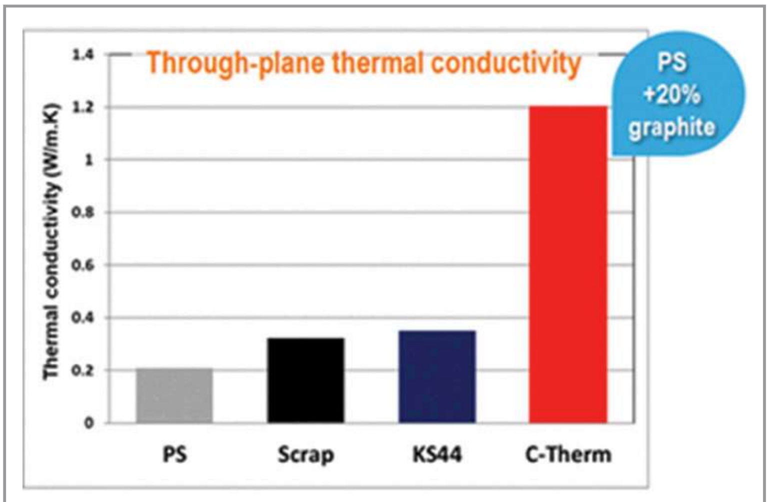


Figure 5: Through-plane thermal conductivity (measured by laser flash) of PS and graphite-PS compounds produced via internal mixer and compression moulding
Source: Imerys Graphite & Carbon

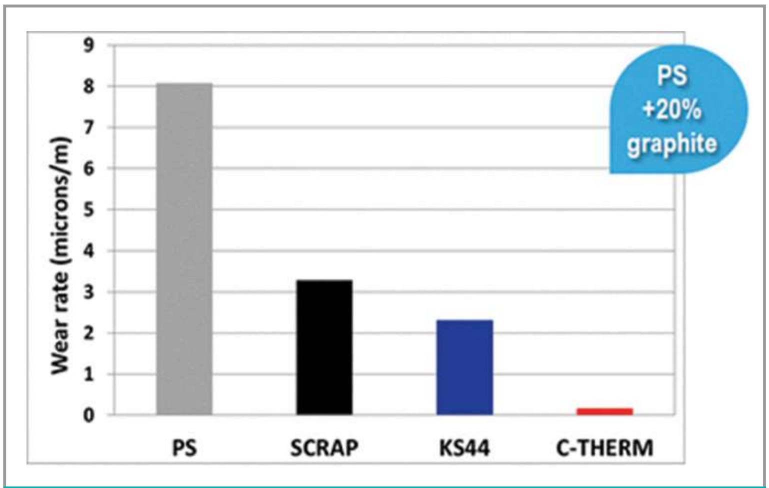


Figure 6: Wear rate of graphite-polystyrene compounds measured using ball-on-three-plate method at constant rotational speed (500rpm) and force (30N) against steel ball
Source: Imerys Graphite & Carbon

not only to thermal and electrical conductivity, but also to lubrication and wear resistance, gas and moisture barrier performance.

Heat dissipation

"High thermal conductivity additives are of particular interest in self-lubrication applications, where they contribute to frictional heat dissipation," says Ellett. "Compared to standard graphites, the high aspect ratio Timrex C-Therm will provide superior thermal conductivity at lower loading (typically half the loading is needed to reach the same performance), lower friction coefficient, and lower wear rate. This makes C-Therm an additive of choice for high-end self-lubrication compounds, where it outperforms low purity, low crystallinity secondary graphite scrap and even high purity and high crystallinity natural and synthetic graphites."

Avanzare Innovación Tecnologica has launched three new AvanThermal masterbatches to enhance thermal conductivity of plastics and elastomers using graphene nanoplatelets in PE, PA or EVA carrier resins. "These masterbatches multiply the thermal conductivity of the base polymer by three or four times with low impact in processability," the company says.

Due to an extremely high aspect ratio, greater than 10,000, graphene nanoplatelets allow the creation of a highly effective thermally conductive network in the polymer matrix. Thermal conductivities of the masterbatch products range from 13.5 W/m·K (AvanThermal 440 50PE MB) through 15.2W/m·K (AvanThermal 440 50PA6 MB) to 16.5W/m·K (AvanThermal 440 50EVA MB).

"As a visual example, if we introduce two injected samples previously heated to 70°C (one made of neat polymer and the other containing AvanThermal 440 50PE MB) in the same quantity of water at the same initial temperature, a difference of 5°C can be measured within five minutes," says Elvira Villaro Ábalos from Avanzare's R & D department. "While the neat specimen just increases by 1°C, the reinforced one increases by 7°C."

Building concepts

Thermally conductive materials are not only of interest in the electronics sector. Spanish research organisation **Aimplas** is currently involved in two projects covering applications in the construction sector. The Habitatge 2020 project covers advanced construction materials that can reduce the temperatures of buildings and urban centres and includes development of PE pipes with enhanced thermal conductivity for use in solar collectors.

According to Aimplas, the first validation tests of the polymer prototypes showed yields of 50% were achieved. "This is a very interesting value since solar collectors manufactured with copper pipes obtain performance values of 50-60%," says Arsenio Navarro, a researcher covering Construction and Renewable Energies at Aimplas.

"We designed a small-scale solar collector (0.52m^2), which we monitored during part of June. We have proved that it is possible to build a solar collector made entirely of plastic materials, including highly conductive polymers [polyester resins as well as PE]. This opens the door to new improvements in this type of product, as well as new ideas in active façades, heat sinks, heat

IMAGE: AVANZARE

Right: This infrared camera image shows the difference in temperature of compounds with and without Avanzare's graphene nanoplatelet additives

IMAGE: EISENHUTH/IKV

Above: Injection-moulded bipolar plates, heat exchanger rings and battery housings made of highly filled graphite compound

recovery systems, etc," he says.

The second construction industry project – EfficientHeating – focuses on manufacturing of thermally conductive PE foils for use in underfloor heating applications. "Through the Joule effect, we have developed a new, 100% recyclable underfloor heating system, with a consumption of less than 50kW/m^2 and lowest carbon footprint compared to current underfloor heating systems," claims Navarro. He says the new solution produced emissions of less than 300 kgCO_2eq/m^2 compared to the 1,500 to 2,500 kgCO_2eq/m^2 typical of current solutions.

Switzerland-based sealing solutions supplier **Datwyler** is expanding its in-house capabilities in the area of thermally conductive and EMI shielding materials. It launched its Project ETEMI in 2020 to develop enhanced functionality sealing technologies for hybrid and battery electric vehicles.

"As the trend towards electrification continues to gather momentum, the ability to conduct electricity and heat, as well as to shield certain components from electromagnetic signals, is increasingly important. Project ETEMI is the driving force behind the creation of an entirely new category of materials - those designed to fulfil the highest requirements in terms of sealing technology, in addition to delivering the aforementioned capabilities in a safe and efficient manner," says Luana Lettieri, Manager Material Development at Datwyler.

The company says ETEMI will be the catalyst for the creation of a material matrix whereby electrical and thermal conductivity and EMI shielding can be coupled and decoupled to suit a wide variety of applications.

The drive away from fossil fuels has revived interest in some quarters in hydrogen fuel cells. Many see the development of highly electrically and thermally conductive plastic compounds suitable for series production of key fuel cell components such as bipolar plates as key development driver for hydrogen utilisation.

The German research association **IKV** is launching a cross-industry network to cooperate in the development of reliable, cost-efficient and long-lasting components for hydrogen applications including fuel cells.

"We will identify the scientific and development-related challenges that need to be tackled in the next few years for the best-possible integration of plastics into the hydrogen economy," says Prof Dr-Ing Christian Hopmann, Head of the IKV. More information about the programme can be found **here**.

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