EXTRA:
Electronics

[VEHICLE ENGINEERING] [MEDICAL TECHNOLOGY] [PACKAGING] [ELECTRICAL & ELECTRONICS] [CONSTRUCTION] [CONSUMER GOODS] [LEISURE & SPORTS] [OPTIC]

Direct Packaging of Components

Thermoset Injection Molding of Packages for Electronic Devices

Thermosets are being increasingly used for packaging electronic devices, and offer good properties for this application. Direct overmolding of the components is particularly interesting here. However, achieving a successful product requires striking a balance between processability, thermal conductivity and reproducibility.

Thermoset materials have a track record of industrial use dating back to 1908 [1]. That makes them the oldest synthetic polymers. Even now, these materials are continually finding new applications. Thermosets reached a peak in the second half of the 20th century, when their good thermal and chemical resistance played a major role in most areas of application. However, they have diminished in importance in recent decades. Nevertheless, developments in the electronics and automotive industries have given thermoset components a new lease of life in recent years. A focus here is the protection of sensitive electronic devices, such as sensors. At Robert Bosch GmbH, too, ever more electronic devices are being provided with thermoset packages, often by means of direct packaging.

In direct packaging, an electronic device, for example a control unit or sensor, is directly overmolded with a thermoset molding compound. The thermoset forms at least an adhesive bond with the packaged components and, at the same time, often also forms the subsequent device package. The thermomechanical properties of thermosets are a special advantage here, especially the low thermal expansion and virtually isotropic properties in the plane. Seen quantitatively, thermoset molding compounds typically have a thermal expansion of the order of copper ($17 \cdot 10^{-6}\,K^{-1}$ or aluminum ($23 \cdot 10^{-6}\,K^{-1}$). The thermal expansion of the circuit board is similar to that of the molding compounds used. The nearer the coefficient of expansions are to one another, the lower the mechanical stresses are under cyclic thermal loads. Thermoset molding compounds therefore offer ideal prerequisites for use as encapsulating materials. A typical temperature application range for direct packaging is between –40 and 150 °C.

In direct packaging, the electronic devices or components are directly overmolded with the molding compound

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More Gentle Processing Compared to Thermoplastics

The processing properties of thermosets also favor their use for packaging sensitive devices. During filling, i.e. when the degree of curing is low, thermosets show the lowest viscosity (mold temperature > material temperature). The encapsulation can therefore be done especially gently. With thermoplastics, the viscosity in the mold (mold temperature < material temperature) increases rapidly and consequently the components to be encapsulated are subject to greater stress. In addition, very low-viscosity thermoset formulations exist for both transfer molding and injection molding, which allow very low cavity pressures to be realized [2]. A disadvantage of the materials is the curing that occurs during processing, the influence of which should always be taken into account in considerations about process reliability.

The advantages of direct packaging that should be particularly stressed are, among others, its high functional integration, reduced number of assembly steps and the improved reliability, for example regarding soldered connections [3, 4]. On the other hand, a significant challenge for direct packaging of electronic devices is the dissipation of excess heat, which may reach a considerable level especially in automotive applications. In a conventional housing, heat dissipation is often achieved by connecting to a cooling structure. Since plastics are generally thermally insulating materials, corresponding functionalization is necessary, for example by adding thermally conductive particles.

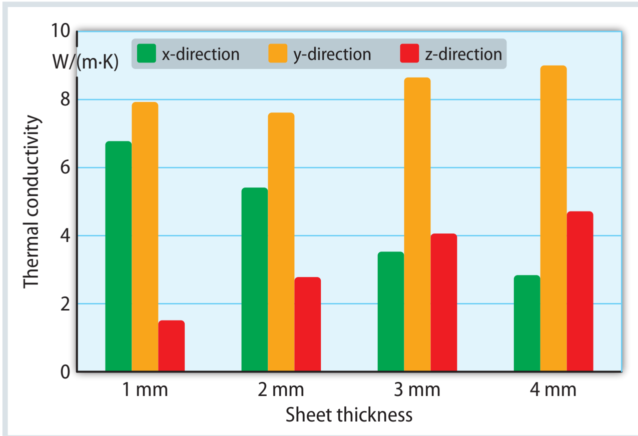

Fig. 1. Thermal conductivity depending on the flow direction for different sheet thicknesses: with increasing sheet thickness, the thermal conductivity decreases in the x-direction and increases in the z-direction
Source: Robert Bosch GmbH; graphic: © Hanser

Special Features of the Filling Behavior

Filling in the case of thermosets is normally described by a so-called block-shear flow. This filling behavior is triggered, for example, by the thermal conditions and resulting viscosity profile: while the material in direct contact with the mold is heated very rapidly and the viscosity is reduced correspondingly, the viscosity in the interior is higher because of the lower temperature. Correspondingly, the material is strongly sheared, particularly in the peripheral region, resulting in a filler orientation induced by the flow. In the interior, a statistical orientation of the fillers is assumed. Based on studies with magnetic and thermally conductive fillers, it was possible to demonstrate this behavior for different sheet thicknesses (**Fig. 1**) [5, 6]. Thermally conductive fillers with a platelet shape, such as hexagonal boron nitride, also show a similar behavior. Small platelet thicknesses, in particular, show a pronounced orientation of the fillers in the flow direction, while with large platelet thicknesses, the thermal conductivity is highly pronounced in the z-direction.

There is only a limited range of thermally conductive materials available for use in thermoset molding compounds. Nevertheless, some commercial materials are available. The thermal conductivity of thermoset molding com- »

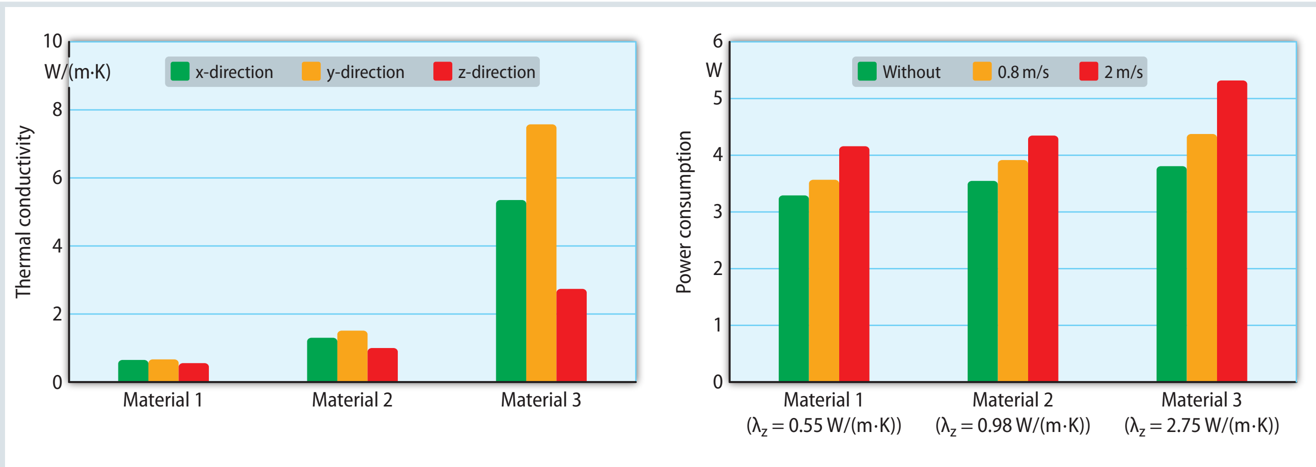

Fig. 2. Thermal conductivity (left) and power consumption (right; with/without convection) for 2 mm thick sheets of different thermoset molding compounds: the thermal conductivity and power consumption of the materials increase disproportionately to one another Source: Robert Bosch GmbH; graphic: © Hanser

pounds extends from values in the range from 0.5 W/m·K (standard material) to 8 W/m·K (thermally conductive polymer). However, the measurement method used plays an important role. For the measurements in the present case, the test unit NanoFlash LFA447 from Netzsch-Gerätebau GmbH was used. A special sample preparation allows the thermal conductivity to be recorded in all spatial directions, which is of great importance for thermal simulations and for part design.

Power Loss and Thermal Conductivity not Proportional

In addition, the materials were checked for heat dissipation under free and forced convection, and special heat removal structures, such as pins and ribs were molded on directly in the injection molding process [7]. It was found that the recordable power loss does not rise in proportion to the thermal conductivity (**Fig. 2**). A high dosage of the fillers, which generally leads to a strong price rise of the materials, does not inevitably result in an improvement of the thermal conditions in the packaged device.

The process of direct packaging is normally included at the end of the value-creation chain. The requirements on feasibility and reproducibility of the process are therefore correspondingly high. An error occurring in the process, for example due to a pressure spike during filling as a result of fluctuations in the material or process, can damage the electronic components. Since, in addition, the molds are often multicavity for cost reasons, the monetary damage can very quickly become very high. Due to the absence of a non-return valve, special attention is therefore paid to reproducibility particularly during thermoset injection molding. Besides the use of materials with low viscosities to minimize the cavity pressures as far as possible, precise process control is also necessary.

To permit this, the cavity pressure was investigated at Bosch during packaging with various materials. Whereas standard material shows very low cavity pressures of about 10 bar, they are already significantly higher for the thermally conductive material (**Fig. 3**). The filling behavior is also very different. With standard material there is virtually no difference between the pressure measured close to and distant from the gate. Only a small pressure increase close to the gate during filling is noticeable. With the thermally conductive material, on the other hand, the pressure close to the gate increases

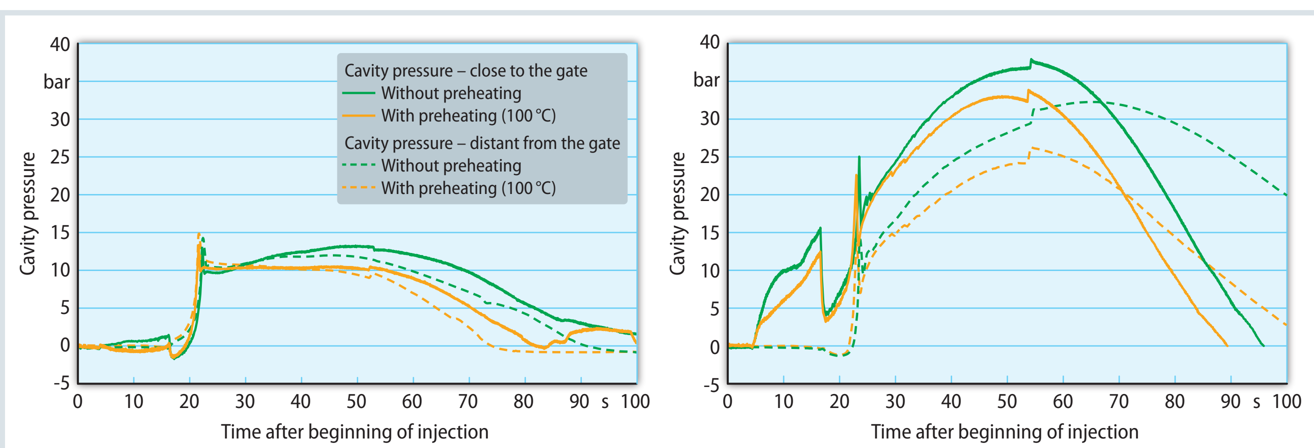

Fig. 3. Comparison of the cavity pressures for materials with lower (left) and higher (right) viscosity: at lower viscosity, the cavity pressure is significantly lower Source: Robert Bosch GmbH; graphic: © Hanser

strongly during filling, which is another sign of the material's higher velocity. Although a slight improvement regarding thermal conductivity can be achieved by increasing the temperature of the insert, the mentioned pressure rise can already be clearly seen.

Failures with too High Cavity Pressure

The effect of the cavity pressures and filling behavior can be very readily assessed from microsections of the packaged electronics. In the investigated case, the sensitive devices were represented by an SMD (surface-mounted device) and a THT (through-hole technology) electrolytic capacitor. Both components show signs of failure at cavity pressures over 50 bar. While in the case of the SMD electrolytic capacitor, a slight indentation of the housing can be seen, with the THT electrolytic capacitor, predominantly the rubber cap is pressed in. At even higher cavity pressures, complete failure of the device eventually occurs (**Fig. 4**).

Another fault pattern is caused by the viscosity of the materials and the resulting stresses during filling. This may result in displacement of the capacitor in the flow path direction (**Fig. 5**). The contacts are bent and the rubber cap is also pressed in. The filling step can thus lead to failure of the device. In addition, the mounting and connecting technology also includes even more sensitive devices such as bond wires, for which the permissible stresses are even lower.

Besides the difficulties in encapsulating electronic devices described above, there are also other challenges. They include, e.g., air inclusions in the component, delaminations between molding compound and device, deformations of the circuit board and solder point damage, as well as the necessary underfilling of components. Depending on the device and components, this list can »

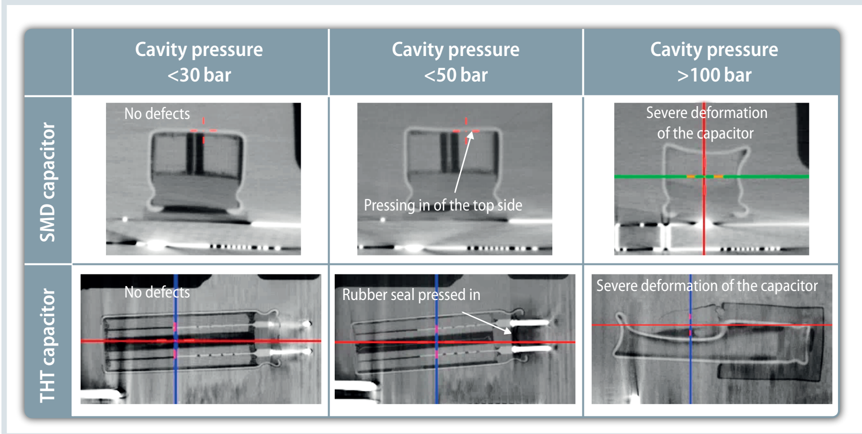

Fig. 4. Fault patterns in SMD and THT electrolytic capacitors: higher cavity pressures can lead to damage of the devices Source: Robert Bosch GmbH; graphic: © Hanser

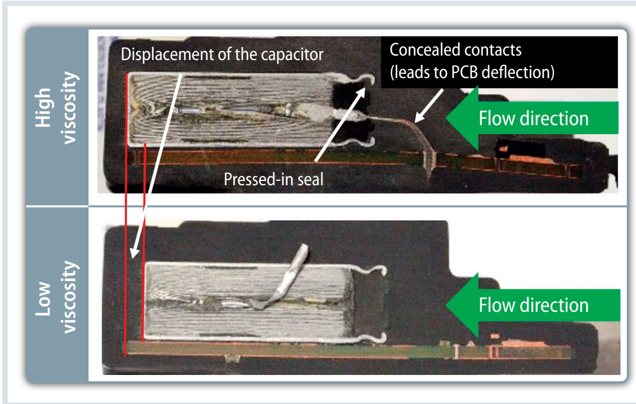

Fig. 5. High-viscosity materials may result in displacement of the capacitor and consequent damage during filling (PCB = printed circuit board)
Source: Robert Bosch GmbH; graphic: © Hanser

be further extended. Good process control is therefore all the more important. However, a suitable method for designing the part and process is required.

The reproducibility of the material and process play a key role in the packaging of electronic devices. As mentioned above, electronic packaging is the last stage in a long process chain and the financial risks in the event of rejects are correspondingly high. Even minor changes in the processing properties or boundary conditions can have an influence on the process quality. It is essential to have a suitable strategy for material qualification as well as process control.

Differences between Simulation and Reality

Besides real influences on the process and devices, virtual product development at Bosch is increasingly moving into the spotlight. To be able to minimize the above-described problems in advance, a correspondingly reliable process and structure simulation is necessary. Although filling simulation already provides very good results, e.g. as regards the filling behavior and occurrence of air inclusions and weld seams, quantitative evaluation still has room for improvement. Particularly as regards predicting process pressures during thermoset injection molding, some programs show clear differences between the measured values (**Fig. 6**). In addition, obtaining reliable material data is often a challenge for process simulation with thermosets.

In the example shown in **Figure 6**, the required pressure (specific hydraulic pressure) during mold filling has been underestimated for a good decade. The cavity pressure is also not correctly modeled by the simulation. Perfect pressure transmission appears to be present, which is not the case in reality. Other focuses in improving thermoset injection molding can be found in the area of the loads to be expected for fitted components and in predicting the lifetime of the packaged electronic components. ■

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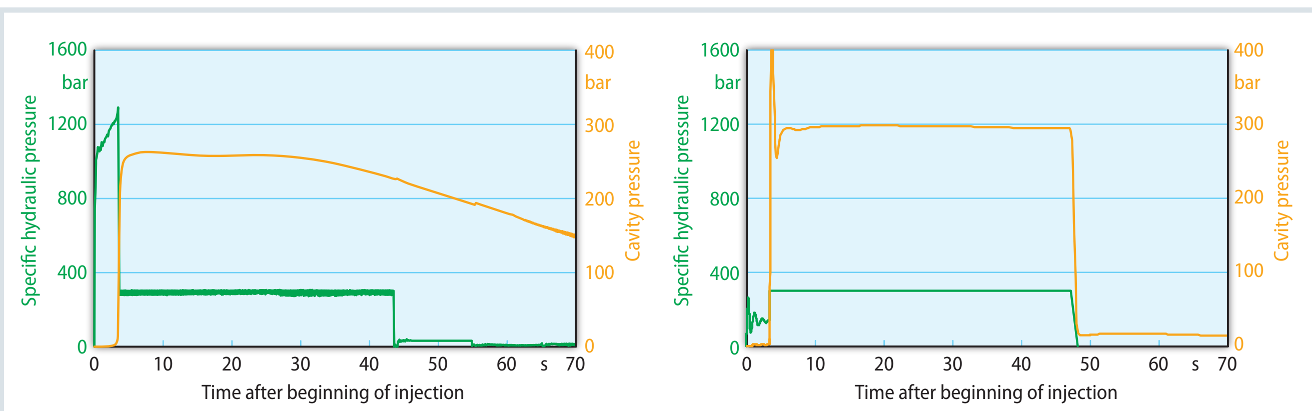

Fig. 6. The comparison of real (left) and simulated (right) process pressures during thermoset injection molding discloses significant deviations in the simulation Source: Robert Bosch GmbH; graphic: © Hanser