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1 *Phenolic resin pellets.*
2 *Fully automated injection molding machine to process pourable thermoset materials and thermoplastic injection molding granules.*

INJECTION MOLDING OF FIBER-REINFORCED THERMOSETS

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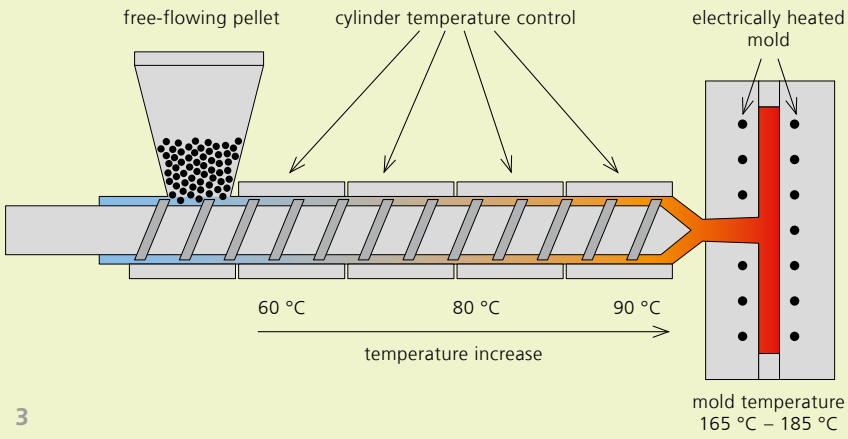
Thermosetting (crosslinking) polymers have several advantages compared to thermoplastics in terms of their chemical and temperature resistance. They are an attractive, high-performance material under challenging conditions. For example, die-cast aluminum can be partially replaced by thermosetting compounds based on phenolic and epoxy resins, leading to a reduction in both weight and costs.

Materials

In thermoset injection molding, it is important to distinguish between moist polyester compounds (bulk molding compound, BMC) and dry, pourable thermoset granules. Fraunhofer ICT focuses on the processing of these pourable molding compounds (figure 1). Depending on the field of application, the molding compounds contain a filler and fiber fraction of 40 to 80 weight-%. Predominantly inorganic fillers (milled glass, mineral fillers) and glass fibers are used for technical applications. Usually, the phenolic resins are novolac-based and their curing reaction is initiated by the decomposition of the hardener hexamethylentetramine (hexa). Below the decomposition temperature of the hardener, the compounds mostly behave like thermoplastics, which means that they can be melted and cooled reversibly.

Process

For the processing of fiber pourable thermoset compounds, an injection molding machine KraussMaffei 550/2000 GX is available at Fraunhofer ICT (figure 2). There is no fundamental difference between the thermoset injection molding process and the injection molding of thermoplastics.



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The differences apply mainly to the temperature control of the process and the geometry of the plasticizing unit (figure 3). Along the material flow in the machine, the temperature is increased, from 30 °C at the material inlet, to 80-90 °C at the screw tip and up to 185 °C in the injection mold, where the curing reaction takes place. The curing time can be estimated as 10 s per mm wall thickness, which is comparable to the cooling time of high-temperature thermoplastics. A compressionless conveying screw in an oil- or water-tempered barrel is used to achieve a gentle melting of the material.

Advantages and applications

Due to the chemical crosslinking of the thermoset material, no melting of the cured part is possible, so the parts exhibit a high temperature resistance. Directly after molding, the glass transition temperature is already higher than the mold temperature, (i.e. > 185 °C). Using a tempering process, it can be increased to 250 °C, if required by the application.

Furthermore, phenolic molding compounds have an excellent resistance against aggressive media, making them predestined for applications in the direct vicinity of a combustion engine. Typical application examples are oil and water pumps, valve blocks and components of the exhaust gas systems.

Due to the high filler content of up to 80 % by weight, the molding compounds have a low shrinkage and a low coefficient of thermal expansion, which is in the range between aluminum and steel. They are therefore very well suited as high-precision parts like pump housings and valve blocks. In a research project at Fraunhofer ICT, a cylinder housing for a one-cylinder combustion engine was designed, developed, manufactured and validated (figure 4). By substituting the phenolic aluminum die-cast with a glass-fiber-reinforced phenolic molding compound, the weight could be reduced by 20 %. Furthermore, acoustic advantages due to the material dampening of the polymer could be observed.

Machinery

The injection molding machine KraussMaffei 550/2000 GX at Fraunhofer ICT is designed for the processing of pourable thermoset molding compounds. It has the following characteristics:

- screw diameter 60 mm
- max. dosage volume 792 cm³
- max. injection pressure 2430 bar
- max. injection volume flow rate 848 cm³/s
- clamping force 5500 kN
- comprehensive functions for injection-compression molding

For a comprehensive characterization of materials, a modular and variable trial mold for injection molding and injection-compression molding is available.

3 *Plasticizing unit for pourable thermosetting molding compounds.*
4 *Research engine with integrated lightweight cylinder casing (Fraunhofer ICT).*