More Precision for Sensitive Fast Curing Compounds

APC plus from KraussMaffei Now Available for Thermosets

They offer high stiffness, are heat and chemically resistant and flow freely into the machine: we are not talking about high-performance thermoplastic resins such as PEEK or PPS, but thermoset polymers. For processing these challenging materials, the large series specialist Baumgarten automotive technics employs the APC plus machine function from KraussMaffei. As a result, rejects have fallen significantly.

There is a gulf between metal and thermoplastics. If – as with brake pistons that must withstand temperatures over 400 °C, or components for oil pumps – the parts must be dimensionally stable in the long term under high thermal loading or robust with respect to aggressive media, then there is an opening for materials that are generally not on the radar of many product developers: thermosets. These materials are particularly economically attractive. Geometries that require subsequent machining when produced by, e.g., heavy die casting can be produced off-tool here. Moreover, conventional thermosets have a lower density than aluminum. Additionally, filler contents of up to 80 % in the matrix (based on phenolic, epoxy, polyester, melamine or urea resin) decouple the material costs from the erratic oil price. However, their thermal and shear sensitivity, the high proportion of fibers and fillers, as well as significant batch fluctuations, make thermoset processing a matter for specialists – and achieving constant shot weights becomes a challenge.

Baumgarten automotive technics GmbH has processed thermosets in mass production for 60 years, and, with its 75 employees, supplies complex technical parts to various markets, such as the automotive and energy industries. Where there is a requirement to replace metal, the company adapts the article geometry to the polymer and independently develops mold and overall production concepts. Moreover, Baumgarten is available as an expert and consultant on all questions regarding thermoset polymers.

Key to the vacuum pump cover is the absolutely flat functional surface (right). The challenge here is that the pronounced rib structure on the reverse side (left) must not show through on the flat side. This can be solved by using PF thermoset compounds (© KraussMaffei)

Since 2017, two production lines at the automotive suppliers' headquarters in Burbach, Germany, have been operating with the APC plus machine function from KraussMaffei (APC = adaptive process control). APC plus analyzes the current process state and continuously compares it with the learned reference curve. The changeover point and holding pressure profile are automatically adapted according to the mass pressure.

Less Fluctuation in the Cavity Pressure Signal

Baumgarten started the project in 2016, as a type of incoming goods testing, as an improved way of investigating batch fluctuations. For this purpose, the predecessor version APC was installed on a machine of the hydraulic CX series with 1600 kN clamping force, which produces the lid of a vacuum pump (**Title figure**). However, the high filler contents were found to be a problem, prompting KraussMaffei to adjust the system as part of the development of APC plus. Now, the data for a wide variety of thermosets are also stored, such as those for the material-specific compression curve, allowing the viscosity of the mass to be constantly measured and the changeover point from injection to holding pressure to be controlled inline and individually in every shot.

The benefit extends well beyond a simple analysis: in the case of an oil-pump

Fig. 1. Precision parts with only 10 µm tolerance: the oil pump adjusting ring of PF (MD+GF) 70. Production has been running since 2014 in continuous three-shift operation on a CX 200 (© KraussMaffei)

adjusting ring of PF (MD+GF), which is produced in large quantities on a CX 200, reject rates are significantly reduced. The part has been produced since 2014 in continuous 3-shift operation (**Fig. 1**) and is an unobtrusive example of high precision in continuous operation. Since it regulates the oil pressure in the motor, it must be dimensionally stable at temperatures of -30 to +140 °C for the lifetime of a vehicle. The height tolerance is only 10 µm. The surrounding medium is an aggressive mixture of oil, water, additives and other substances. In addition, static and dynamic forces are active, since, pushed into the end position by means of springs, the oil pressure acts against the valve.

Even before APC plus was introduced, Baumgarten already monitored the cavity pressure as the main quality criterion and, inline, automatically rejected parts with values that deviate too much. A 48-hour test (24 hours without and 24 hours with APC plus) has now shown that, with activated machine function, the range of cavity pressure variation is significantly reduced (**Fig. 2**): the variation coefficient sank from 4.10 to 2.51 %. Outliers resulting from variations in grain size, filler or dust contents, are compensated and the tolerance window can be made narrower.

Incidentally, if intensive analyses are required, the downward variations in cavity pressure are particularly interesting: the deviation from a tolerance value of ±30 bar can call the part quality into question. Fractured flow fronts could negatively influence the part strengths and, in addition, impair the surface properties.

Same OFT Value – But Different Material Behavior

The aim is to use APC plus to investigate other phenomena, too, in future. What happens if the viscosity index changes strongly, but the part has the same quality criteria? What takes place in the process, then? Realistic analyses such as these are much more valuable for processors than test methods such as the orifice flow test (OFT), which takes place outside the machine. Its purpose is to determine the flow/hardness ratio of the free-flowing molding compounds, but is a hybrid of reactivity and viscosity. That means that a material with low viscosity and high reactivity can reach the same OFT value as a material with high viscosity and low reactivity – but behaves entirely differently in the machine.

Baumgarten's own ambition, to gain an ever better understanding of thermoset materials, has gained the company a reputation as an expert, whose advice is sought by customers – and also by thermoplastic processors, who have recognized the outstanding material properties and are therefore looking to expand their sphere of activity. However, the latter do not in general dare to enter uncharted territory, but look for a proj- »

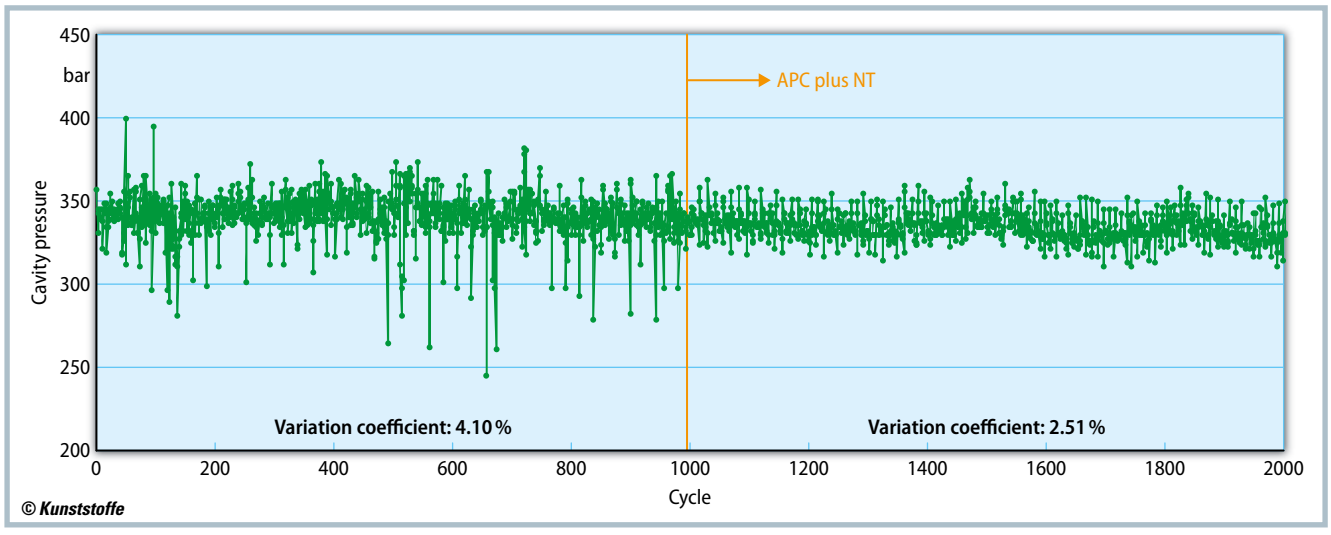


Fig. 2. A 48-hour test (24 h without and 24 h with APC plus) shows that the machine function significantly reduces the fluctuation band of the cavity pressure (NT = non-thermoplastics) (source: KraussMaffei)

ect partner, since thermosets require considerable process experience.

It starts with the fact that the material must be stored in a controlled way, since it is sensitive to its history, which includes transportation. Thus, thermosets "remember" the temperature and moisture effects, which in turn require a precise assessment and modification of the process. If the storage is too moist, too warm or just too prolonged, the material is damaged, leading to fluctuations in the process. Since its abrasiveness place heavy loads on the tool and machine, special steels must be used – Baumgarten even prescribes the production process for the commissioned tools in detail.

During processing, the thermally initiated reactivity due to fluctuations in the melt temperature or residence time can lead to polymer curing starting already in the plastification unit, which makes it impossible to use a check valve. Because of the high filler contents (30 to 80 % at Baumgarten) and the low processing temperature compared to thermoplastics, the molding compound are hardly compressible at all. As a result, the minimum deviations in the residual mass cushion or at the start of filling, which is not visible to the operating personnel in the process, are directly reflected in the injected volume. Without the possibility of automated correction, one would be helpless in the face of these mechanisms.

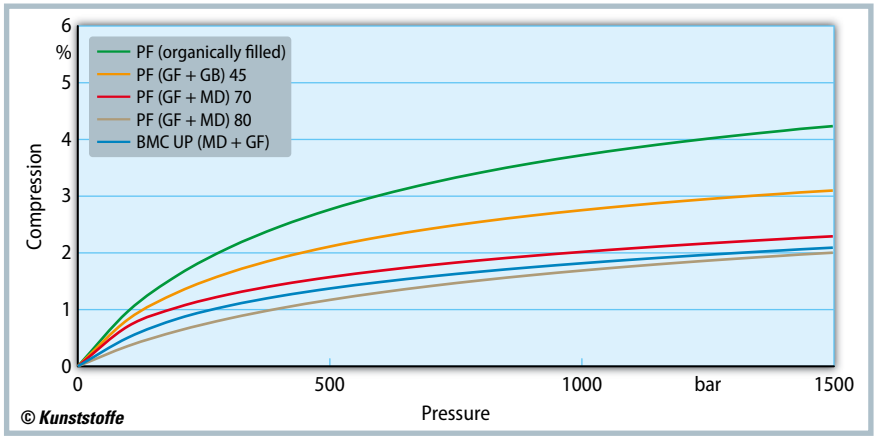


Fig. 3. The more highly filled, the lower is the material-specific compression curve. At 1000 bar pressure, the mass column of an organically filled PF is compressed by 3.7 %; at 80 % filling of glass fibers and mineral components, it is only 1.8 % (source: KraussMaffei)

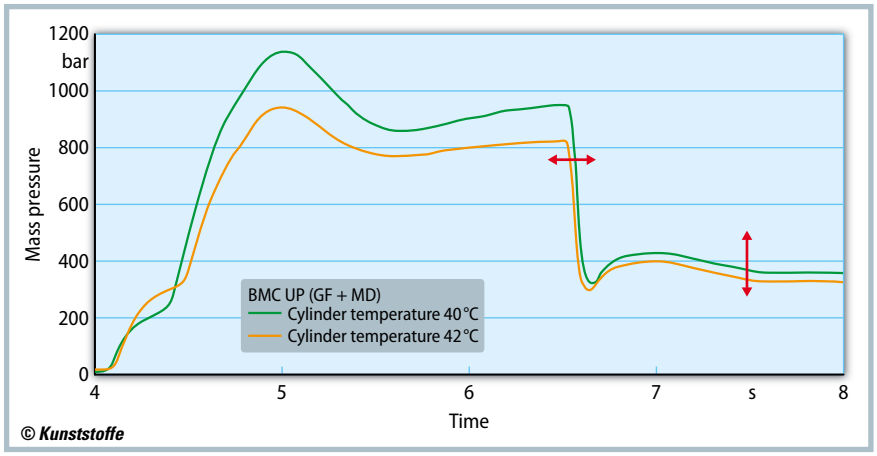


Fig. 4. If the cylinder temperature rises by 2 °C, and the mass becomes less viscous, APC plus switches to holding pressure at an earlier point and reduces the pressure level to prevent overfilling of the part (source: KraussMaffei)

The Volumetric Filling of the Cavity Remains Constant

These fluctuations are compensated by APC plus – both for free-flowing thermosets and BMC (bulk molding compound) as well as liquid and solid silicones (LSR and HTV/HCR). The stored material-specific compression curves provide the prerequisite for this (**Fig. 3**). Here, one can see that, for example, the mass column of an organically filled phenolic resin is compressed by 3.7 % at a pressure of 1000 bar in the cylinder. But if the filler consists of glass fibers plus mineral components and the degree of filling is 80 %, the compression is only 1.8 %. For comparison, a thermoplastic PP is about 8 to 9 %.

To keep the system user friendly and take into account the greater frequency of fluctuations in the filler content, the user can easily choose between lower and higher degrees of filling in the free-flowing thermosets. The fact that APC plus is based on the material-specific compression curves is its unique selling point and is the characterizing feature of the patent [1] published in 2015.

In the process, APC plus adapts the changeover position and holding pressure level such that the volumetric filling of the cavity remains constant (**Fig. 4**). If, for example during BMC processing, the cylinder temperature rises by 2 °C, which can quickly occur if the temperature control unit is subject to drift, or in the summer heat, the plastic becomes more fluid and the APC plus switches from injection to

The Authors

Dipl.-Ing. (FH) Cordula Wieland works in Product and Technology Management at KraussMaffei Technologies GmbH, Munich, Germany; cordula.wieland@kraussmaffei.com
Nicolina Topic, M.Sc., works at KraussMaffei in the field of machine technology development; nicolina.topic@kraussmaffei.com
Dipl-Wirt.-Ing. Jan Hirz is Head of Sales & Project Management at Baumgarten automotive technics GmbH, Burbach, Germany; j.hirz@bat-duro.com

Service

References & Digital Version

- You can find the list of references and a PDF file of the article at *www.kunststoffe-international.com/7337092*

German Version

- Read the German version of the article in our magazine *Kunststoffe* or at *www.kunststoffe.de*

holding pressure earlier (horizontal arrow). In addition, the holding pressure level (vertical arrow) sinks. Both are performed in order to avoid overfilling of the component.

Insidious disturbance factors, such as ambient factors, batch changes and in particular fluctuations that occur unpredictably from cycle to cycle, are thus automatically adjusted and compensated in the same shot by the machine function. The operating personnel is usually unaware of these factors. However, employees must be familiarized with the new mode of action so that – following the previous sequences – they do not intervene when abnormal effects are seen. The employees must know that the machine automatically keeps the filling volume constant, and be able to rely on this.

Parts with Higher Shot Weights – Trend and Challenge

The (too) early crosslinking of thermosets is one of the biggest challenges on the way to higher shot weights, since the complex process is ever more difficult to master with increasing volumes. Baumgarten currently operates KraussMaffei machines with clamping forces from 800 to 3000 kN and screw diameters from 35 to 70 mm. Products for the automotive industry are produced here by the million, such as thermoset brake pistons, which are well established in the USA with about 1.3 billion units but have not yet made a breakthrough in Europe.

High-precision components for fluid pumps are also produced, for delivery to customers worldwide. However, there are ever more requires for articles weighing 2 kg and more. The energy sector is showing particularly high growth rates here. Besides durability and stability, electrical insulation and leak tightness are also required, which makes it interesting to use thermosets. Electronic components can be overmolded with epoxy resin molding compounds to seal them against media; such thermosets form a firm bond.

Large-Series Application

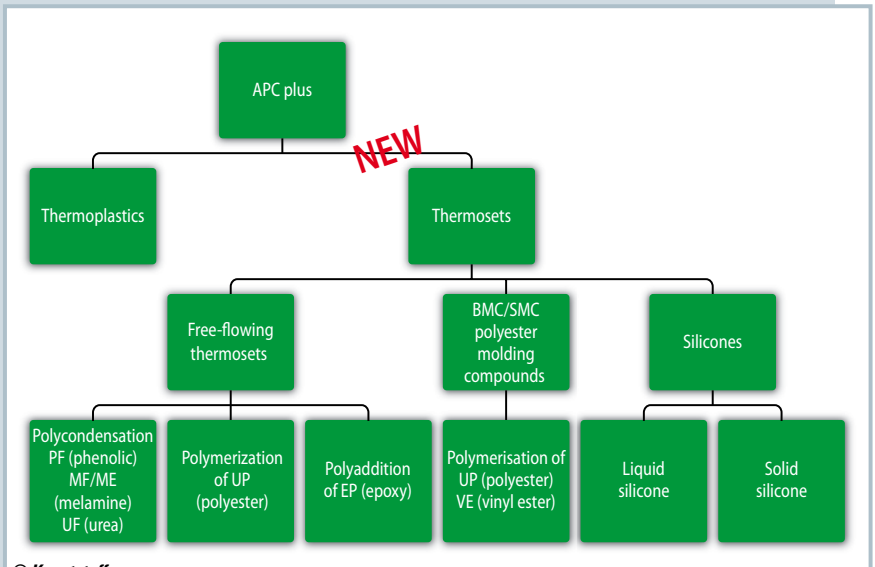
KraussMaffei and Baumgarten have enjoyed a trusting relationship for 35 years, as is shown by the rapid implementation of APC plus (**Fig. 5**). The possibility of testing APC plus in large series application on thermosets was a stroke of luck for both parties. With their cooperation, the machine manufacturer and the processor are also pursuing the goal of creating more opportunity for this often neglected domain of polymers within plastics processing. Training and study courses tend to focus on thermoplastics, so that developers usually do not know much about the diverse opportunities offered by thermosets for producing robust, durable parts. Baumgarten intensively exchanges information on this with leading universities, such as the RWTH Aachen and the KIMW in Lüdenscheid, Germany. The faster the progress in the energy and mobility sectors in developing systematically weight-reduced electric cars, the more injection-molded thermosets can benefit. ■

Fig. 5. The project team for the integration of APC plus in the thermoset large series (from left): Nicolina Topic (KraussMaffei), Linus Schneider and Jan Hirz (both of Baumgarten), and Cordula Wieland (KraussMaffei)

(© KraussMaffei)

APC plus Performance Range

Besides thermoplastic processing, the performance range of KraussMaffei's APC plus now also covers the entire spectrum of thermosets (see Figure). The injection molding of thermosets is a challenging process, since its reproducibility is made difficult by (too) rapid curing, high filler contents and the backflow of the material during injection. The APC plus machine function keeps the filling volume constant – both for free-flowing thermosets and for thermoset polyester bulk molding compounds. Baumgarten automotive technics GmbH, one of the first companies to employ APC plus in this field, significantly reduced its reject rate.



© Kunststoffe