Nobel Prize for Injection Molding

Visible and Invisible Innovations Continue to Confer Benefits on the Industry. And on Mankind, too?

Lightweight construction, small batches, and progressive integration of electronic functions: general industrial trends are spilling over into the injection molding industry. Recent years have seen the development of remarkable solutions for meeting all kinds of requirements. Machine manufacturers have not been idle though: precision-regulated processes form the basis for many applications, and now it seems that the self-optimizing injection molding machine is no longer a fantasy.

For the overmolding of continuous-fiber-reinforced PP, the planar polyamide sheets are first heated up safely and gently in the gripper system of a six-axis robot and then, at a precise molding temperature, handed over to the Lipa mold (figure: Arburg)

Have you ever wondered, why there is no Nobel Prize for engineering excellence? Perhaps one word is missing there: yet.

The eponymous Alfred Nobel, who amassed great wealth as an industrialist, had no children and so he arranged for his fortune of about 31 million Swedish kronor to be used to establish a foundation. The interest from this fund, decreed Nobel in his will, was to be "annually distributed in the form of prizes to those who, during the preceding year, shall have conferred the greatest benefit on mankind". More precisely, he wanted awards for winners from five disciplines: physics, chemistry, physiology or medicine, and literature, and peace. Nobel stressed that no consideration be given to nationality, but that the most worthy should receive the prize.

An anomaly in the ranks of awards conferred annually since 1901 is the "Nobel Prize for Economics". The Alfred Nobel Memorial Prize in Economic Sciences, as it is properly called, came into existence in 1968 and was founded by the Swedish Riksbank to mark the occasion of its 300-year existence. Although the award criteria are similar, many critics believe that it is more the outcome of lobbying.

Against this background, the plastics processing industry might well consider whether it would be beneficial for it to award a similar prestigious prize. It would have to give some consideration as to who or what should be honored. And whether the criteria would reward either good ideas and their realization, or rather a benefit accruing to mankind. Perhaps just benefiting the industry would do as well.

The following non-judgmental overview looks at recent innovations in injection molding, but makes no claim to completeness. It is left to readers to decide the

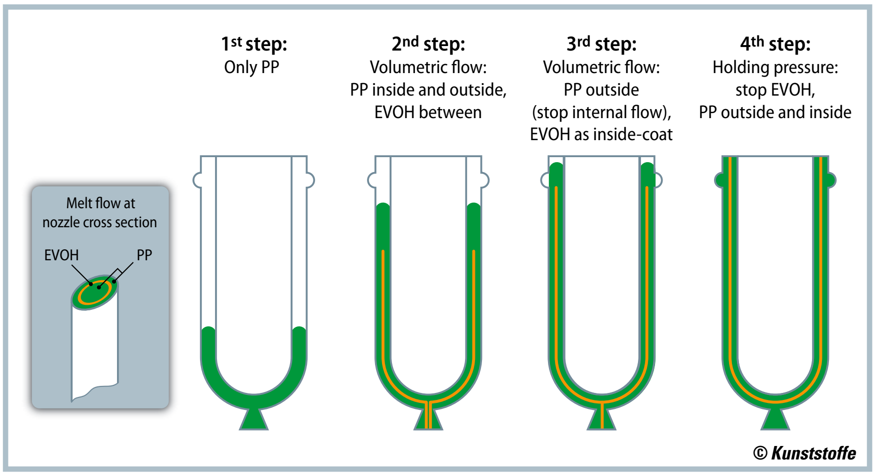

Fig. 1. Barrier molding can be controlled so precisely that the wafer-thin inner layer is distributed uniformly over the entire container (figure: C. Jaroschek)

Fig. 2. Cans made from tinplate and aluminum are now facing competition from plastic (figure: Milacron)

significance of the various developments for the industry at large or even just their own company.

Barrier Molding of Food Cans

The use of plastics often raises interesting issues. In the packaging sector, diffusion of oxygen into containers is a problem. Extrusion blow-molded products can benefit from co-extruded, very thin layers of substantially oxygen-impermeable polymers (EVOH or PA) that serve as an inner layer. The same effect can be achieved with barrier molding.

Unlike its sandwich counterpart, this consists in feeding two polymer melts into the cavity at roughly the same time through a coaxial nozzle. The thickness of the evenly distributed diffusion-protection layer can be very readily regulated via the volumetric flow of the inner barrier component – the latest advances have reduced the layer thickness down to a few tenths of a millimeter. Developed by US company Kortec, the underlying technology was presented in its basic form as long ago as K 2007 (**Fig. 1**).

Last year, Kortec became part of the Milacron Group, which had only just acquired hot runner manufacturer Mold-Masters. By virtue of these and other acquisitions, Milacron has gone from machinery maker to system provider while at the same time strategically expanding its expertise, especially in packaging production. Whereas Kortec had acted as think tank and commissioned third-parties to make the technical components, Mold-Masters now makes the specialty hot runners, and Milacron supplies the complete systems. Barrier molding can be retrofitted to existing machines, in which event an additional injection unit developed by Mold-Masters, along with its own controller, is required.

The important market for food cans is potentially a high-volume one that is being revolutionized by the so-called "Klear Can". Made from polypropylene, these cans are only able to offer an extended shelf life by virtue of the inner barrier layer of EVOH (**Fig. 2**). Kortec claims to have already equipped 32-cavity molds with its co-injection technology for producing plastic cans.

Electrically Conducting Components, Metallized with Specialty Coatings

Many plastic components are part of a module or serve as a housing for protecting an assembly. The functionality of the plastic component can often be greatly extended by rendering it electrically conducting. Molded interconnect devices (MIDs) are well established in this area and essentially comprise a board with soldered-on electronic components and housing in one. One such example is the finger of a robot hand (**Fig. 3**), the outcome of a project that was conducted as part of the interdisciplinary cluster of excellence entitled "Cognitive Interaction Technology" (Citec) at the University of Bielefeld, Germany.

MIDs can be produced in various ways, each of which involves subsequent electroplating. As an example, parts can be overmolded with two components, one of which is electroplatable. For finer circuit structures, recourse can be made to laser direct structuring (LDS). In this case, the injection molding materials are seeded with metal nuclei. After injection molding, they are "laser structured", a process in which the laser beam ablates very fine layers of plastic from the component surface to expose the metal nuclei.

The resultant plastic components can then be given a nickel or copper finish by chemical means. This entails depositing metal atoms from a liquid solution onto the tracks structured by the laser. These continuous metal tracks can be thickened electrochemically as necessary.

A novelty in the LDS method is the use of coatings containing metal nuclei. The benefit here is that non-nucleated components can be electroplated locally. For this purpose, a coating is applied to a base substrate and structured with the laser. This possibility now affords a way of producing metal parts as MIDs (**Fig. 4**) – which is particularly beneficial in the production of LED bulbs, because the metal body can readily dissipate the substantial amount of heat generated on the back side facing away from the light. These coatings can also serve to convert prototypes produced by methods such as »

Fig. 3. Finger of a robot hand as an MID component. The laser process not only creates the 3-D structures, but also makes the interconnects (figure: LaserMicronics)

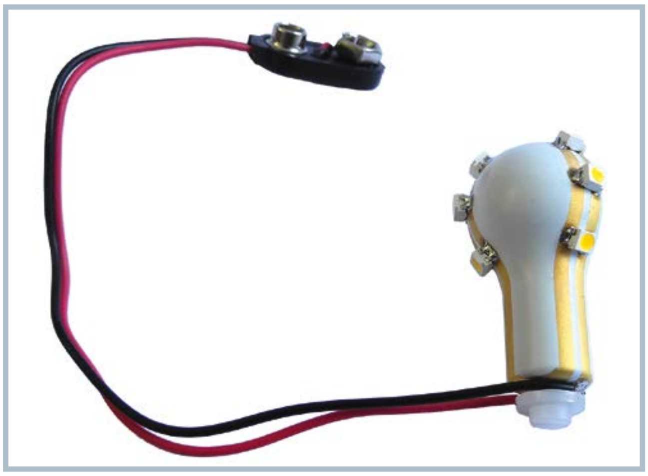

Fig. 4. The aluminum base is coated with a special powder and thus becomes amenable to LDS (figure: LPKF)

stereolithography, selective laser sintering and fused deposition modeling into MID components.

Integrated Metal-Plastic Molding

Sometimes simple is best. Integrated metal-plastic injection molding (German abbreviation: IMKS) came about when the Institute for Plastics Processing (IKV) in Aachen, Germany, and toolmaker Krallmann combined thermoplastic injection molding and metal die casting on a single machine to conserve resources. There have been many attempts in the past to render plastics electrically conductive and to directly produce components with electrical functionality by means of overmolding. In IMKS, the feed solder is processed directly as a melt. Soft solders based on tin and lead melt at about 200 °C near the eutectic region and, at about 6×10^6 S/m, offer approx. 10 % of the conductivity of copper.

For applications that do not require very high electrical performance, it is no stretch of the imagination to consider replacing all copper wiring with solder. This development dates from 2009 and a series of experiments aimed at determining how far a soft solder melt can flow at different wall thicknesses and channel widths in a type of flow spiral. Recently, Krallmann developed a handy little melting unit with an injection plunger that can be bolted directly onto the mold.

This is a simple, essentially multi-component process that was unveiled back then when it was used to produce table lamps in a three-station mold (**Fig. 5**) – so it is already in the public domain. That is not to detract in any way from the underlying innovation, however. After all, everyone should be aware that successful projects are often based on simple ideas – they just need to be discovered.

Fig. 5. The table lamps are produced by the 3C method: polymer base and insulation sandwiching an overmolded solder track (figure: Krallmann)

Conductive, Capacitive Films

Canatu, a leading Finnish manufacturer of transparent conductive films, showcased in partnership with the Schuster Group and Display Solution AG a pioneering three-dimensional encapsulated multi-touch sensor for the automotive industry. The demonstrator is an example of a multifunctional display with 5-finger touch (**Fig. 6**). Automotive designers have long sought to integrate touch panels in 3-D freeform into dashboards and center consoles, but a suitable technology proved elusive. That is, until a few months ago, when the three partners presented the first solution.

A special film is printed with invisible conductive carbon nanobuds (CNB in-mold film). The film is first patterned to the required application and then back-molded in the IML process. Thanks to its bending radius of 1 mm, the film can conform to nearly all surface shapes, and it can be stretched 120 % and molded without loss of conductivity. Companies such as plastic electronic, the Leonhard Kurz Stiftung with its subsidiary PolyIC, and a collaboration between Kunststoff Helmbrechts and MID-Tronic, have stepped on similar paths.

Flow-Coating with PU

Optimization of plastic surfaces is a never-ending quest: how might components with a permanently attractive finish be produced without the need for costly downstream processes?

The ColorForm process solves many problems in surface finishing and was developed jointly by KraussMaffei Technologies, a plastics machinery maker, Duro Automotive Systems, an automotive subcontractor, and Panadur, maker of the highly versatile polyurea coating system. ColorForm essentially is a two-step injection overmolding process in which the second step involves a two-component polyurea coating instead of a thermoplastic.

The two coating components are mixed shortly before reaching the cavity and injected at a temperature of about 70 °C onto the surface of the hard component molded in the first step. In recognition of the low viscosity of the polyurethane system, this is more often referred to as flow-coating. The non-crosslinked coating mixture can flow over long distances at an average layer thickness of 0.3 mm, and even around tight radii. The crosslinking reaction has been adjusted to enable the flow-coated components (**Fig. 7**) to be removed with a gripper after a few seconds, without the suction pad making marks on the surface.

Crosslinking is complete several hours after production. The coating system is solvent-less and crosslinks to a very rugged finish. It passes various mechanical and chemical stress tests without significant deterioration, compared with powder-coated reference samples.

This process confers a wide range of benefits. Unpigmented coatings are clear and create a very attractive depth effect at a layer thickness of 0.3 mm. Pigmented coating systems can hide all blemishes on the preform, such as weld lines and differences in gloss. The low-viscosity coating can reproduce almost any shape and so allows logos to be applied readily and attractively to surfaces – but unfortunately not contrasted or multicolored.

The feel of the PU system can be varied from paint-like to leathery. Whereas ColorForm, which is already established on the market, yields high-gloss, matte or textured solid color surfaces depending on the quality of the mold surface in the flow-coating cavity, it has been joined by a new, extended variant that offer new design freedom that is more conducive to up-market and simultaneously more rugged metal-effect surfaces (see the article on page 85 – *ed.*)

Dynamic Mold Temperature Control

The rule for conventional injection molded parts has always been: the higher the mold temperature, the more faithfully the plastic melt reproduces the surface structure of the cavity. This poses something of a conundrum because thermoplastic melts need to cool as quickly as possible so that the component is rigid enough to be ejected – and that means the mold temperature must be as low as possible.

This can be resolved by temperature cycling, i. e., rapidly changing the surface temperature of the cavity within a cycle. The idea here is to generate the highest-possible temperature at the time of injection so that, depending on the power density, heating can coincide either with the end of the cooling phase or with the opening of the machine. As soon as the melt strikes the cavity surface, the switch-over to cooling can take place.

To be sure, this technology does not sit squarely with the modern-day prioritization of energy efficiency. Nevertheless, it has gained considerable traction in recent years. Various technical solutions »

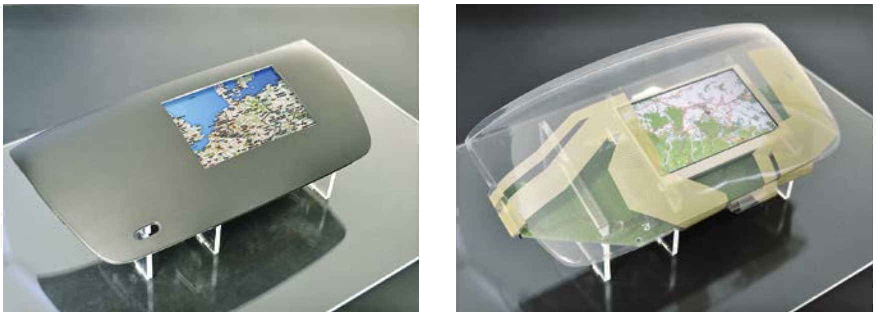

Fig. 6. Touch-sensitive panel demonstration part. The film printed with transparent conductor tracks is back-molded in the IML process – the transparent plastic panel in the figure on the right permits a view of the interior (figure: Display Solution)

Fig. 7. Coating of components in the mold is done by flow-coating with a PU surface (figure: Krauss Maffei)

exist, the simplest of which employs temperature control units with two circuits; when properly programmed, these can alternately heat and cool.

Local problem zones – such as long thin cores – are addressed by the vario GT from gwk. The temperature medium used here is carbon dioxide. This is a liquid at pressures greater than 50 bar at room temperature. If it is expanded in the mold area, phase transition and hence marked cooling occur. The resulting gas can be returned to the temperature-control unit and heated there to temperatures above 300 °C. In this state, it can be used for heating the mold (**Fig. 8**).

Inductive heating of a mold area is a more energy-wise approach. Introduced in 2008 under the name "Indumold" by Kunststoff-Institut Lüdenscheid, Germany, it has been further developed by RocTool. Basically in inductive heating, electricity is used to heat the mold surface. However, due to the thermal conductivity of the steel, a part of the mold beneath the surface is heated too. This is necessary for preventing the temperature from dropping too rapidly as soon as the induction heater has been switched off. Because only a very limited mold area has been heated, cooling is very rapid and energy consumption is very low.

According to RocTool, the cavity region of such a 3.5 t mold is heated with approx. 100 kW from 85 to 170 °C in 5 s. This represents a relatively low energy input of 20 kJ. Alternative technologies that heat the mold from the inside out, inevitably heat up larger areas, as a result of which power consumption is automatically higher.

Elsewhere, manufacturers continue to tighten the screw as they seek to boost energy efficiency. The lion's share of the energy consumed by an injection molding machine is needed for heating the barrel and rotating the plasticizing screw during metering. Dr. Boy is specifically targeting these consumers by optimizing the plastification process. The use of an EconPlast unit, says the manufacturer, can cut the demand for heating energy by up to 40 % and energy losses during metering considerably. This has been accomplished by improving the heat transfer efficiency and the precision of the temperature control unit. The system also shortens the start-up and warm-up times and lowers scrap rates because the processing method is material-friendly and generates less friction.

Genuine, but Invisible Innovations

In practice, it is not just a question of boosting the productivity, efficiency and availability of machines and system solutions, but also of increasing process stability and reliability. This is where the barely visible innovations come into play.

To date, standard practice has been to rely on feed-back controlled injection molding machines, whose movements remain consistent from cycle to cycle. However, when the quality of the input material changes and, with that, the flow properties, the settings on the machine must be readjusted in order that the component quality will not change. In the past, the solution here was to employ adaptive feedback control which used actual values from previous cycles and a quality correlation as a way to to adjust the setpoints. Particularly worth mentioning in this regard is the Lego process [1], in which the injection pressure is continually adjusted to the average flow number of the last ten cycles. For over 30 years, Lego bricks have been molded under the principle of pressure limitation, i.e., the injection rate slows down due to the pressure limitation as the cavity fills up. The selected pressure limitation also matches the holding pressure. Consequently, filling with slow-flowing melts automatically takes longer. Thus, the flow number increases and the pressure is revised up-

Fig. 8. The heating unit (foreground) feeds CO_2 which has evaporated in the cooling phase back into the process to heat the mold in the next cycle (figure: gwk)

ward in subsequent cycles until the flow number again corresponds to a predetermined reference cycle.

Today's high-speed computer chips now make intra-cycle correction possible. This is the operating principle behind the software packages of two machine manufacturers – iQ weight control from Engel and APC (Adaptive Process Control) from Krauss Maffei – which automatically adjust the switching point and the holding pressure (**Fig. 9**).

The APC approach is to measure the injection pressure and form the integral value during the injection process once an automatically specified start melt pressure has been reached in a likewise specified constant measuring time. Because the curve of the injection pressure for each mold has a characteristic shape and shifts either upward in the case of highly viscous melt or – as a function of when the non-return valve closes – to the left or right, this measured integral value (viscosity index CI) must be constant in relation to the overall filling index.

The overall filling index is the integral of the injection pressure over the overall injection time. For a known reference cycle, this yields a ratio of viscosity index to filling index. With the aid of this ratio and the viscosity index deviating from a reference, a new filling index for the current cycle can be determined. If, for example, the non-return valve now closes a little later than in the reference cycle, measurement of the filling index also starts after a delay, with the result that the calculated filling index is reached later. As a consequence, the switchover takes place later.

If the flow properties and thus the injection pressure change, the holding pressure will be readjusted in proportion.

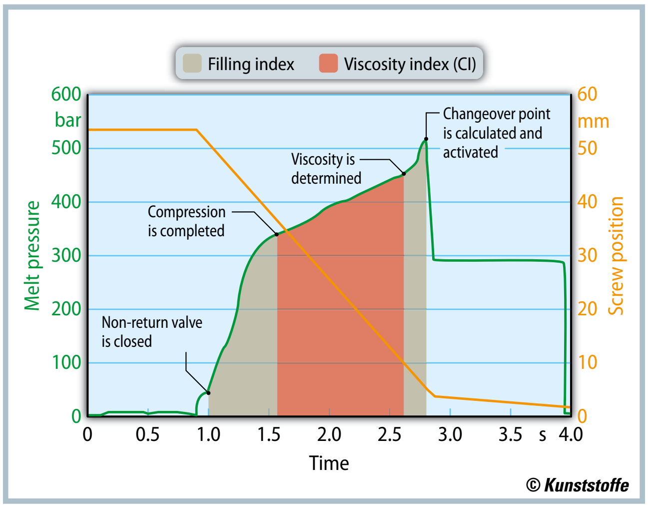

Fig. 9. How APC process control works: If material variations cause a change in flow properties and injection pressure, the holding pressure is proportionally adjusted in the same cycle (figure: KraussMaffei)

In this way, variations in quality and/or production scrap can be substantially reduced. This is especially important for processing of recycled materials or recycled admixtures where fluctuations in flow properties are virtually inevitable – here, automatic adjustment of process parameters proves especially useful.

Engel also offers in the iQ product family a solution for improved mold breathing. Normally, it is not necessary to reduce the machine clamping force, provided that aluminum molds or molds that really are too small for the machine are not used. The "iQ clamp control" software adjusts mold breathing via the clamping system's force sensor. For a given reference cycle, the clamping force is automatically reduced until mold breathing reaches a defined level at which flash is just prevented. As a result, venting of the mold is facilitated. If the injection pressure changes due to a material changeover or addition of recycled material, the clamping force can be automatically adjusted so that flash formation remains suppressed. There is less burden on the operator, because he no longer has to worry about the clamping force whenever settings change.

Fig. 10. A tape made from PA and carbon fibers can decisively strengthen the mechanical properties of a component (in this case, a demonstrator) (figure: Ems-Chemie)

Lightweight Construction with Continuous Fiber Reinforcement

It is surprising that the subject of lightweight construction has faded from the public eye since K2013. Nevertheless there can be no question of inactivity: a typical example of many ongoing activities is the Open Hybrid LabFactory in Wolfsburg, Germany, which, as a registered association with close ties to the University of Braunschweig develops along with several industrial partners mass-production technologies for the economical and environmentally sustainable fabrication of hybrid lightweight components from metals, plastics and textile structures. The entire value chain for hybrid components is represented: from conceptual design through the production of carbon fibers and the hybrid production process through to recycling.

Lightweight construction is still in the development stage and will remain an important issue. Besides polyamide sheets, continuous fiber lay-ups look very promising (**Title figure**). One innovation in this field is a product marketed under the name "Ems Tape Technology" (ETT) by Ems-Chemie. This concerns continuous fiber-reinforced tapes in which all the fibers lie precisely in the tape direction and are fully impregnated with polyamide. A great many applications have just a few areas that need to be mechanically » reinforced. These areas, such as weld lines, can be greatly strengthened with the tapes, for example. In partnership with the Swiss Advanced Technical College at Rapperswil/Switzerland, Ems developed technologies for inserting the tapes and studied the characteristics of a purpose-built demonstration part (**Fig. 10**).

The study shows that a single tape achieve as much as double the strength of a weld line. The resultant bending strengths are achieved virtually regardless of the structure of the base part, and irrespective of the degree of orientation, or even if there is a weld-line-induced weakness. Other properties, too, such as creep, long-term, alternating and pulsating fatigue strength, are also improved.

Fig. 11. An injection molded adapter, which in turn is over-foamed for larger EPS components again and thereby makes particle foams suitable for assemblies (figure: Krallmann)

Injection Molding Composites with Particle Foams

Lightweight construction can be understood in different ways. For some, it means using plastic as an alternative to steel, but it must offer comparable or even superior mechanical properties. In that case, there is no avoiding of fiber-reinforced materials. For others, it simply means striving to achieve the lowest possible weight for an application. In that case, polystyrene is recommended. At first sight, particle foams, such as expanded polystyrene (EPS), have nothing much in common with injection molding, as there are too many geometric restrictions.

One solution here is particle foam-injection molding developed by Krallmann and Ruch Novaplast in partnership with injection molding machine maker Arburg over a number of years. First, a preform of conventional EPS is overmolded with a thermoplastic material. This creates, for example, an adapter that reproduces a defined metric thread (**Fig. 11**). EPS is sufficiently heat- and pressure-resistant to survive the overmolding process intact, provided that a defined process window is observed.

This adapter itself can now be further processed in a foaming mold to yield larger assembly units. In particle foaming, superheated steam heats expandable styrene beads above their glass transition temperature, after which their blowing-agent content causes them to expand and fuse together. The preform of the adapter, of course, is heated at the same time and forms a firm positively bonded unit with the fused polystyrene beads. Recent developments now aim to integrate the two processes on one machine. Perhaps we will find out more about this at the K next year.

This process combination opens up diverse applications, e.g., in the areas of mobile devices, electronics housings, power tools, car interiors, car body parts, fasteners and many more besides. And all because a molded adapter liberates the particle foam from (almost) all restrictions. With conventional fastening methods, in contrast, it is very difficult to integrate a particle foam component into assemblies.

Fig. 12. Injection molding with a new zirconium alloy is an efficient way to faithfully reproduce the finest structures (figure: Liquidmetal Technologies)

Metal Injection Molding without Powder or Nuclei

Although plastics are highly versatile, there are applications for which metals are more suitable. Because injection molded parts offer extensive geometric design freedom, processes designed to injection-mold metal parts have been developed in the past. These include metal powder injection molding (PIM) and thixomolding.

Engel recently unveiled together with Liquidmetal Technologies a new process. The centerpiece of these is an alloy of zirconium, with fractions of Cu, Ni, Al and Ti, that has a melting point of 785 °C and solidifies largely as an eutectic. Unlike the case for thixomolding, there is no two-phase system of melt and crystal nuclei at processing temperatures of 1,100 °C. The melt of this alloy has a low viscosity and solidifies, largely uncrystallized, at rates of more than 10 K/s in molds at a temperature of 250 °C.

Whatever may be said about the finer technical aspects of this alloy, the properties of the material in the cold state are interesting. The material shrinks only by about 0.4 % as it hardens and so supports very precise dimensions. It can be used at about 450 to 500 °C thanks to the recrystallization, is highly elastic due to its elongation of 1.8 %, and is largely resistant to corrosion. In addition, it obviates the need for debinding and sintering that are required in powder injection molding – the machine simply produces finished parts. These properties make the material very attractive for applications in medical technology and small, high-quality luxury goods such as watches and smartphones (**Fig. 12**). This association with "luxury" is justified, because it currently sells for around 150 USD/kg.

For the processing, Engel has developed an injection unit with an integrated induction heater. Ready-made cylindrical alloy ingots are fed to the machine from the mold side, in the manner of a preloader. The mold is then evacuated to prevent the molten alloy from undergoing violent oxidation. Injection itself occurs at high speeds of about 500 mm/s because the material cools rapidly.

For the Little Ones

There is huge demand for tiny components, which are classified as miniature and microstructured types. Microstructured components are generally large and so have a greater need for mold technology with cyclical heating control. In contrast, miniature parts have very small shot weights that require special machine designs.

Arburg has developed a micro-injection unit with a precise feed-back control and short traverse combined with high filling dynamics. It optionally combines an 18 or 15 mm screw for melting the material with an 8 mm injection screw. It can therefore process all conventional materials and standard pellet sizes. The pellets first are compounded on the servo-electrically driven screw preplastication unit, which is arranged at 45 °C to the horizontal injection unit. The flight depths of the plasticizing screw are similar in design to those of a conventional three-zone screw. The molten material is then fed into the injection unit. The 8 mm screw is designed as a pure feed screw, and processes the material on the FIFO principle ("first in, first out"). »

Fig. 13. The M3 Mini production unit, essentially a self-actuating injection mold for versatile production of micro components, is aimed at the market for small runs (figure: MHS)

Fig. 14. In plastic freeforming, the components are generated layer by layer, where necessary, as shown here by the manufacture of a two-part closing slide valve, with the aid of a second (water-soluble) component as supporting material (figure: Arburg)

A completely different system in the guise of the M3 was presented at K2013 by Mold Hotrunner Solutions (MHS), a Canadian hot runner specialist. In essence, this is a self-actuating injection mold with four groups of cavities which are each filled via an integrated pneumatic injection plunger. From a process point of view, the conventional injection and holding pressure process has been scaled down to smaller dimensions. As the clamping force limit is never reached in the case of small injection molded parts, even under high injection pressures, the process can run consistently isochorically, which translates to very high process stability with low feed-back control outlay. This self-actuating mold is locked via electromagnets. The melt is provided via a screw preplastication unit.

Since K2013, a number of feasibility studies have shown through their differences just how application-specific and at the same time highly diversified is the field of micro injection molding. Realizing that not every application spawns annual volumes of more than 100 million pieces, which is the capacity of the M3, MHS is now following up with the smaller M3 Mini, which is aimed at the market for smaller quantities (**Fig. 13**). The manipulated variable here is smaller and the shot volume is greater, but there are fewer cavities. The versatility stems from the arrangement of the nozzles in the hot runner and the parts handling.

The trend is thus moving away from the traditional injection molding machine and shifting more towards automation and process control. Modules must therefore be a flexible match for each other in order that the overall production cell may meet the specific customer requirements. Experience with all kinds of materials and particularly with engineering thermoplastics such as PC or PA is proving very positive so far.

Freeforming without Mold

An all-encompassing trend is the demand for ever smaller production batch sizes. The reason for this is the widespread desire for custom products, the number of which is set to escalate on account of "Industry 4.0". This is a very uncomfortable development for injection molding, which is only worthwhile if large runs are involved, due to the high tooling costs.

Injection molding machine maker Arburg has laid down a marker here by developing a new machine for additive manufacturing (type: Freeformer). Basically, the plastic melt is injected into the open, i.e., processed without mold. The method is commonly emoployed in rapid prototyping, where it is called fused deposition modeling. It entails continually melting a plastic thread in a heated nozzle and discharging it as a melt via a die that can move in two axes. This allows components to be printed layer by layer.

The Freeformer solves two problems inherent in this technique. Conventional FDM suffers from inaccuracy at sharp corner transitions because melt discharge cannot be coupled precisely to keep pace with the movement speeds of the print head. In the Freeformer, the nozzle contains a needle valve system, which operates permanently at high frequency. This injects tiny molten droplets in rapid succession into the layer to be built up.

That is actually the second benefit conferred, for the machine operates with a melt reservoir which supports the use of conventional plastic pellets, which in turn are melted in a small plasticizing unit. The melt is kept continuously under pressure so that it can be ejected when the needle valve opens. At sharp transitions, the needle valve can simply stay closed. When combined with a second discharge unit, the machine can also produce 2C parts or support structures for complex geometries that can be easily removed later in a waterbath (**Fig. 14**).

Conclusion

Some of the innovations presented here are a response to the general trends towards lightweight construction, small batch sizes and "smart plastics." But if any trend stands out from the others in injection molding, it is probably the trend toward combinations with other methods. Injection molding itself is now so highly advanced that innovations target specific product areas. Many machinery makers no longer show off their portfolio as a fleet of machines, but rather provide specially assembled production solutions for various industries.

All that remains now is the question of the Nobel Prize. At this point it should be noted that first of all a consortium ready to provide prize money needs to be found. Then the criteria for awarding prizes would have to be defined. Unlike economics, the innovations presented here certainly have the potential to be recognized by an international general public. ■

The Author

Prof. Christoph Jaroschek teaches mechanical engineering and plastics engineering at the Fachhochschule Bielefeld; christoph.jaroschek@fh-bielefeld.de

Service

References & Digital Version

- You can find the list of references and a PDF file of the article at *www.kunststoffe-international.com/1150132*

German Version

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