Injection Molding 4.0 – Visionary and Tried-and-Tested Solutions

Industry 4.0 Comes to Injection Molding and True Innovations at K 2016

Every three years, the showcase of plastics technology, the K fair, takes place, where one can deduce the current state of the industry. What is occupying the experts today, and what will still be flourishing in the future? The following article describes some of the development paths and trends. At the end of the day, there is a lot of tried-and-tested technology that is being continually refined and improved. There were also some innovative and visionary applications to be seen.

Assembly within injection molding cycle: A turnkey system produced two LSR/LSR wristwatches "ready for use" in 75 s at the K 2016 (© Arburg)

The burning topic of the moment, Industry 4.0, could hardly be overlooked at the show. It might even be easier to list the companies that did not put a focus on this topic. The question of what advantages it offers to users in the manufacturing industry has many and varied answers. In principle, many of the things presented already have a long and familiar track record. As a general consensus, there are three "smart" areas – i. e. areas in which networking or interlinking is advisable:

- Machine,
- production, and
- service.

As regards machines, there are developments in the field of control systems. **KraussMaffei** increasingly regards process constancy independently of possible changes and disturbances caused by the material, for example different flow characteristics as a result of the non-uniform feeding of recyclates. The already familiar APC (adaptive process control) can now not only compensate for the changeover point to the holding pressure phase, but also the level of the holding pressure itself.

Thanks to the unified OPC interface (open platform communications), unlimited amounts of data for a production cycle from the machine can now be stored at centralized locations (data clouds) for subsequent use. In general, no one asks who actually needs this data. Parts can be provided with a QR code, which subsequently links to precisely these production data. Another practical feature is the personalization of parts. At the trade show, products could be manufactured for individual visitors, and the visitor helpfully received an SMS at the instant of production. Nevertheless, for popular exhibits at the show, people stood in line for up to one and a half hours (see ***Kunststoffe international 11/2016***, p. 6).

For service, **Engel** already has some concrete ideas to give customers early warning of a prospective system failure. A new system measures the wear of screws in the installed state. By means of an ultrasonic sensor mounted on the cylinder, it is possible to record the mechanical wear through the cylinder wall and via the melt in the screw flight. An idea that is even more in line with the concept of utilizing networked data is that of recording the wear of the ball screws of electrically operated machines for evaluation by the machine manufacturer. For this purpose, a set of loading conditions is normalized, i. e. made independent of the movement velocities and loads. If the further loading conditions are then recorded, a gradual wear of ball screws can be registered. The problem here lies with the continuous recording, since manufacturers are unwilling to allow themselves to be moni- »

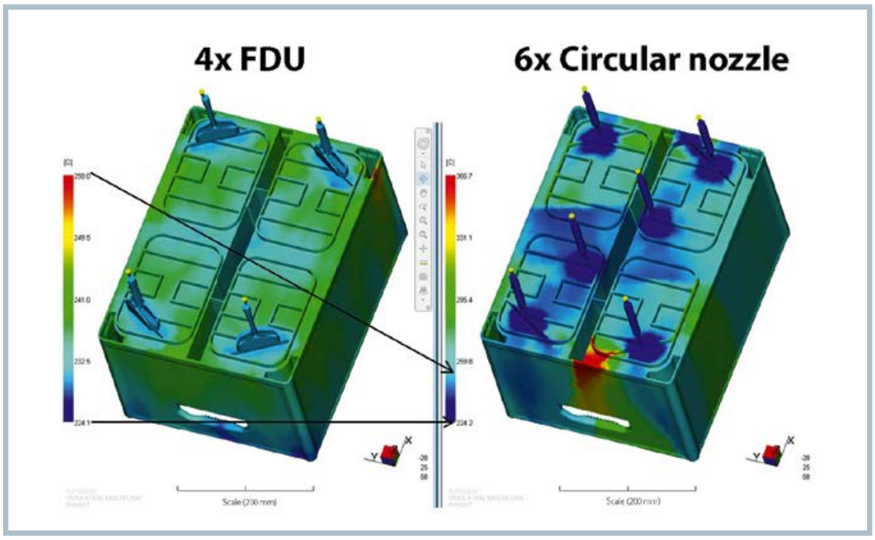

Fig. 1. Four slit nozzles vs. six conventional circular nozzles: The temperature of the melt immediately after injection shows the advantages of low-pressure injection molding (© Haidlmair)

Fig. 2. The M-PET 300 combines all the important components of Milacron's entire product portfolio in a single solution (© Milacron)

tored voluntarily. There are no plans to provide occasional recording for checking purposes, since any load peaks in the event of unpredictable machine events can lead to preliminary damage, and might not be recorded.

Low Pressure Injection Molding

While Industry 4.0 represents the digital present, low-pressure injection molding is a longstanding aspiration. If we could only outsmart the physics and reduce the necessary injection pressures, machines with lower clamping force could be used, or larger flow path/wall thickness ratios would be possible.

Netstal and **Sumitomo (SHI) Demag** use **Plastisud** mold technology for manufacturing very thin-wall packaging by high-speed injection-compression molding. In one case, the melt was injected in 0.1 s into the partially closed 4+4-cavity stack mold with vertical flash face in a mold gap of 1.5 mm width. Before the mold is closed, a holding plate is advanced, which runs around the cavities so that the gap spacing is reliably maintained during injection. Immediately before the end of injection, the pressure on the holding plate is relieved, and the mold closes completely, so that a part thickness of 0.35 mm is established. Because the gap is so large in comparison to the part thickness, the injection pressure remains lower than 1000 bar.

Haidlmair has urged its designers to show their creativity by developing a "bottle crate 2.0" that is futureproof. The first development was not a new crate, but a new FDU die (FDU: flat die unit). The hot runner nozzles no longer resemble pinpoint gates, but are comparable to a slit die. The idea was to drastically reduce the shearing rates in the nozzle region. This reduces the pressure requirement of the hot runner system, so that the overall injection pressure for a comparable crate is reduced by about 20 %. A major advantage is an additional shortening of the cooling time also by about 20 %, because the shear heating is low and the melt as a whole is uniformly cooler after injection into the cavity. That is demonstrated by simulations with the Autodesk (Moldflow) software package, and by tests with typical geometries in 2-cavity molds, in which one cavity was gated using a conventional nozzle and one with the slit die (**Fig. 1**).

Barrier Injection Molding

Thanks to developments by the hot runner specialist Kortec and by the system supplier Husky, barrier injection molding has been state of the art for about ten years. An important element of this is a double hot runner for the container material (PET or PP) and the barrier component. The hot runners guide both melts through coaxial nozzles located directly in front of each individual cavity. A very thin layer of the barrier material (e.g. EVOH) within the part wall prevents the diffusion of oxygen through the packaging, so that foods have a longer shelf life, even with reduced refrigeration. Three years ago, Milacron bought Kortec, thereby acquiring an advantage in the field of preform production.

After **Milacron** reentered the PET machine market at NPE 2015, its European debut followed at the K trade show. The M-PET 300 (72 cavities, preform weight 37 g, cycle time 14 s) is a servohydraulic PET system that combines all important components of Milacron's overall product portfolio in a single solution: machines, clamping units, injection units, hot runner, injection molds and handling systems (**Fig. 2**).

Immediately after the first commercial success of the Klear Can product, Milacron comprehensively demonstrated the advantages of this pioneering innovation. Klear Can is a recyclable, multilayer transparent can of PP with a barrier layer that could soon supersede metal cans for packaging foods with a long shelf life, such as fruit, vegetables, fish, meat and others. Klear Can offers the clear advantage that customers can see the food quality directly at the point of sale. In addition, the packaging is BPA-free and can run through existing filling, seaming and sterilizing equipment in canning factories.

The market demand for multi-layer packages is growing. To meet this need, **Husky** developed the Multi-layer Barrier Technology (**Fig. 3**), which uses a new co-injection system that is built on the company's HyPET HPP5 platform. The hot runner channels are naturally balanced, and a new design distributes the melt streams very accurately. Due to this precise balancing, all cavities are supplied with the

Fig. 3. Preforms for bottles with pigmented barrier layers for different applications. Containers with thick-walled bases do not require a barrier around the gate point (© Husky)

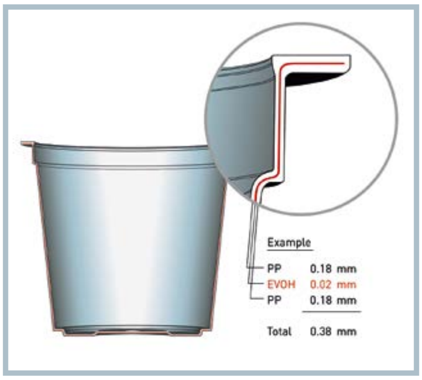

Fig. 4. Precise centering of the cavity cores ensures the barrier is uniformly distributed (© Fostag)

same barrier volume and melt quality, so over a complete shot, an imbalance of less than 1% can be achieved. The system is robust against disruptions, and maintains its precise balance over long run times, without degradation.

The system was designed with ease of use for the operator in mind. From the system HMI, the operator has complete control of mold, machine and drying equipment. The simplified user interface allows the operator to enter the percentage of core layer, start and stop position of the core layer, and the machine automatically calculates the injection profile. System availability was an additional key consideration in the design. The hot runner was designed for reliability and long run times, and in case of resin contamination, it features front access for the nozzles for reduced maintenance time. The system is flexible to run a broad range of barrier resins, and different amounts of core layer for multi-layer applications, but can also run monolayer molds.

Fostag, the specialist in high-performance injection molding applications, focuses its barrier injection molding on coffee capsules with an average wall thickness of 0.4 mm. Here, too, a barrier is important so that the important aromatic substances do not evaporate before the capsule is used. Fostag also attaches great importance to maintenance of the nozzles while the mold is still mounted. A reliable distribution of the barrier between up to 64 cavities ensures the precise centering of the individual cavity cores via square core centering. This allows each individual core to be centered so precisely that the wall thicknesses have hardly any variation at all around the circumferences (**Fig. 4**). The slightest deviations lead to a slight running ahead of the melt at the somewhat thicker cavity side, and therefore to a non-uniform distribution of the barrier components.

In barrier applications, quality control until now has been performed via IR spectroscopy. Each polymer absorbs infrared radiation in particular wavelength ranges. A polymer can be reliably characterized by shining radiation through it and analyzing the wavelength spectrum of the emerging light. Thanks to the IR analysis of preforms, it can be accurately recorded whether individual regions of the part are free of barrier material.

Intravis presented an analytical system based on optical coherence tomography (OCT). This measurement principle can be compared with sonar, except that, instead of sound waves, IR rays impinge on a body in this case. The radiation itself penetrates the body and a small portion is reflected. In this manner, signal can be evaluated across the part thickness. As »

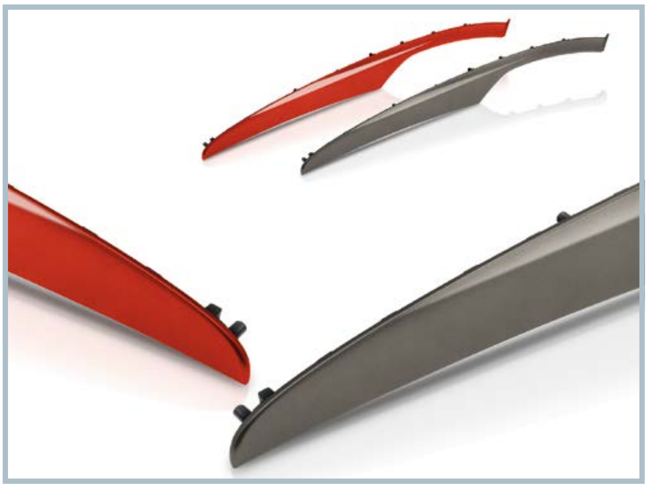

Fig. 5. The door interior trim strips with scratchproof PU lacquering as surface are produced by 2-component injection molding (© KraussMaffei)

Fig. 6. Rotary table of the micro injection molding machine with two independent injection molds for preform and finished part. The blue component is electrically conductive (© Wittmann Battenfeld)

a result, a three-dimensional image of the layer structure of different plastics is obtained, the position of barrier layers can be recorded with micrometer accuracy, and an alarm can be sounded if required.

A similar system was presented by **IMD vista**. In contrast to OCT, terahertz radiation is used here, which has longer wavelengths than IR radiation and can also pass through non-transparent parts. This system was illustrated with the example of Klear Can, and the radiation can even measure through the label on the packaging.

High Quality Surfaces

The optical properties of plastic parts must often satisfy high demands. At the trade show, three process combinations on this subject were presented in a next development step:

- Variotherm molds,
- film back-molding, and
- inline painting operations.

The euphoria for variotherm molds seems to have subsided somewhat in general. This may be because of the higher energy costs that occur for rapid temperature exchange on the cavity surface. With temperatures in the range of the glass transition temperature, the surface reproduction is very faithful. For weld-free parts, it is sufficient to only heat the weld seam region in the mold. With the Z process, **Hotset** offers the possibility of heating local mold regions at heating rates of 60 K/s. The system was developed together with the Kunststoff-Institut Lüdenscheid, Germany.

With backmolding of films, **Engel**, together with its system partners, demonstrated a combination of injection molding with in-mold graining (IMG) as a roll-to-roll process. In IMG, the grain is only transferred to the film as the film is formed on closing of the injection mold. The mold (Georg Kaufmann Formenbau), with the grain finish, is porous (air permeable) for the thermoforming process. The "skins" produced in this way can be further processed by laminating onto a backing, by back-foaming or back-molding. Unlike conventional IMD processes, the formed film remains in the mold and is directly back-molded. Thanks to the use of vacuum-capable nickel shell, grain surfaces with a very high quality grain finish are possible (see article p. 43).

The surface coating with PUA or PU lacquers represents an efficient and environmentally friendly alternative to conventional lacquering. It is free of solvents, plasticizers, heavy metals and does not cause emissions. In addition, the integrated process saves up to 30 % of costs compared to conventional painting processes. It also offers advantages regarding surface quality. The hardness of PU or even PU systems can be adjusted to requirements and can, for example, be made much more scratch resistant than the PMMA-based series coatings produced in 2-component thermoplastic injection molding, which are currently available. The automotive industry particularly benefits from these.

Because of the high scratch resistance together with freedom of design and excellent surface quality, the ColorForm process from **KraussMaffei** is predestined for visible parts, both in exteriors, e.g. pillar covers, as well as in interiors, e.g. trim strips (**Fig. 5**) or other decorative elements in the center console or dashboard. The process only requires a conventional multicomponent injection mold. After the pre-molded part has been transferred to the second cavity, a low-viscosity PU lacquer is flood coated into a small gap. Flood coating means that because of the low viscosity of the 2-component PU compound, hardly any injection pressure is required. The two components are mixed briefly before they enter the cavity via an injection head docked onto the mold.

Multicomponent Technology

The limits of multicomponent technology are often determined by the mold costs, in particular in the case of very small parts. The guiding and cooling of

Fig. 7. Clothes hook as plastic-metal hybrid part. Left: the metal insert, right: the insert, with PBT hook molded on one side (© Plasmatreat)

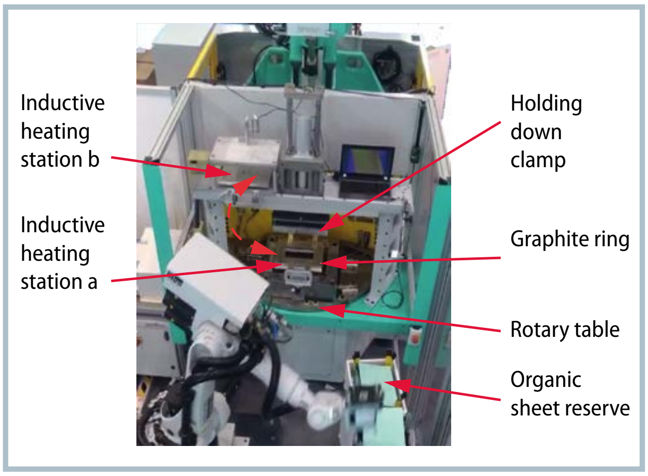

Fig. 8. Plant concept of an inductive heating of one mold half and the heating of a graphite ring for manufacturing a laptop lid (© RocTool, processing: Hanser)

the melt and, in addition, the change of position of the pre-molded part to the position for overmolding, take place in an extremely small space. Here, **Wittmann Battenfeld** presented a rotary table, on which two independent molds can be clamped. Thus, the MicroPower 15/10H/10H small injection molding machine with a single-cavity mold (Ortofon) is used for the transfer of a 2-component plug, which is injection molded from a PC and an electrically conductive PC and is used as a sound pickup-head in record players (**Fig. 6**).

An interesting material combination is the pairing of liquid silicone rubbers (LSR). The material is manufactured from two separate components, which are mixed just before they are molded, so that crosslinking can take place. This enables a third ingredient, e.g. a colorant, to be added to the two components. **Momentive**, together with **Elmet** presented 2-component injection molding with a rotary mold and a very economical machine configuration.

Elmet has prepared a 4+4-cavity mold for production of bicolored egg cups in a fully automated production cells, in which an injection molding machine from Arburg can be combined with proprietary ancillary equipment and feed system. The closed-loop pigment dosing installed in the dosing system is a new option that was presented for the first time at K. This innovation precisely monitors and documents the addition of pigment and additives to the material, which is particularly relevant for applications in medical technology that require a precise amount of the additive in each individual part.

The special system concept also permits 2-component injection molding with only one LSR metering system, on a standardized 1-component LSR injection molding machine. An injection piston for the second component, which is fed with the individual components from the bypass, is mounted directly on the mold. The metering system for conveying the A and B components thus simultaneously supplies the injection unit of the machine and the additional injection piston on the mold.

Arburg has designed a turnkey system specially for the production of LSR/LSR watches: While an electric two-component Allrounder 570 A uses a 2+2-cavity mold to produce two wrist straps from liquid silicone (LSR) in a cycle time of 75 s, two previously produced straps will be completed in the integrated assembly station within the injection molding cycle to produce ready-to-use watches.

A linear robotic system (type: Multilift V15) performs the handling tasks: It removes the injection molded parts and places them in a cooling station. From there the handling system turns the wrist straps over in an assembly station. The watch housings are supplied in the correct position on interchangeable trays and the buckles are provided by means of a conveyor system. A spreading system widens the silicone opening on the wrist strap with two fingers, enabling the robot system to insert the housing. The Selogica control system regulates and monitors all processes.

A completely new type of multicomponent technology was presented by **Plasmatreat** with the production of plastic-metal hybrid parts. Customarily, plastics can only be mechanically joined or bonded to metals. In multicomponent injec- »

Fig. 9. The in-situ polymerization of ε-caprolactam opens up new opportunities for manufacturing fiber-reinforced plastic parts with thermoplastic matrix – not only in the automotive industry (© Engel)

tion molding, a mechanical clasping must usually be provided, in which the plastic can overmold a metal insert simultaneously on the front and back sides, forming a rivet, so to speak. In the Plasma-SealTight process, on the other hand, the metal insert is pretreated so that the plastic that is subsequently overmolded forms a permanent bond with the metal insert with very high adhesive strength (**Fig. 7**).

The metal is pretreated by exposure to a plasma beam, to which a precursor has been added. As a result, the surface of the metal part is enriched with silicon and silicon oxide. The silicon provides very good adhesion of the layer to the metal while the silicon oxide forms a barrier against permeating media and functional groups create good adhesion to the polymer. A very interesting option is to apply layers of approximately 100 nm to selective locations, i.e. at places defined with millimeter accuracy. To cure the layer, the metal parts are briefly preheated under an induction heater before injection molding. Measurements of the bond strength in the tensile shear test provide values of over 20 MPa for bonding steel to PA6-GF30 and to PBT-GF30.

Structural Parts

Plastic parts are sometimes required to withstand high mechanical loads. In such cases, combinations of organic sheet and molded-on plastic geometries are in great demand. Organic sheets are glass or carbon fiber scrims or fabrics, which can be stiffened and connected with a thermoplastic matrix, and can be thermoformed when heated. At their booths, **Engel** and **KraussMaffei** each presented a manufacturing cell with an infrared oven for heating the organic sheets and a handling system for conveying the limp materials to the different process sections.

A variant of this was shown by **RocTool** and Fextronics Manufacturing. The top shell of a laptop consists predominantly of a formed organic sheet with a precisely structured visible surface. The very good surface quality is achieved by pressure forming. For this process, the organic sheet is placed on an inductively heated mold half and pressed over the hot mold side with a hold-down clamp while it is heated on one side. The mold surface is heated from 70 to 265 °C within 40 s.

On the non-visible side, a polycarbonate border is subsequently overmolded to join the top shell to the laptop. For a good bond, this non-visible side must be heated before overmolding. This is achieved with a graphite ring. This ring is also inductively heated at a separate station. Graphite has a high heat capacity and stores the energy, so that the ring can be taken off the inductive heater for heating the rim of the organic sheet, and easily placed on the organic sheet. The temperatures in the graphite ring cycle between 280 and 300 °C in the process, depending on the time and place.

The induction heaters for the mold and the graphite heater are supplied with the same control system with a time delay. Per cycle, the system requires approx. 1.1 kWh for heating the mold and approx. 0.23 kWh for heating the graphite ring. The heating of the organic sheet takes place on the outer position of a vertical injection molding machine with a rotary table, on which two mold lower sections are mounted, with one half each in the region of the clamping unit, where the previously heated and formed organic sheet is overmolded (**Fig. 8**).

As regards fiber reinforcement, Engel takes its own approach with the processing of in-situ polymerized PA. A first system for this was already showed at K2013, which raises the question of whether it is now of academic or practical application. The enhanced system that has now been presented underscores the seriousness of this technology. In the in-situ polymerization, the reactive monomers (ε-caprolactam) are mixed shortly before injection; polymerization then takes place in the cavity (**Fig. 9**). The advantage here is the very low viscosity, which is approximately a factor of 10 lower than the viscosity of the epoxy resins that are used as alternative. Consequently, a good impregnation of the inserted fiber fabric or scrim is achieved, and

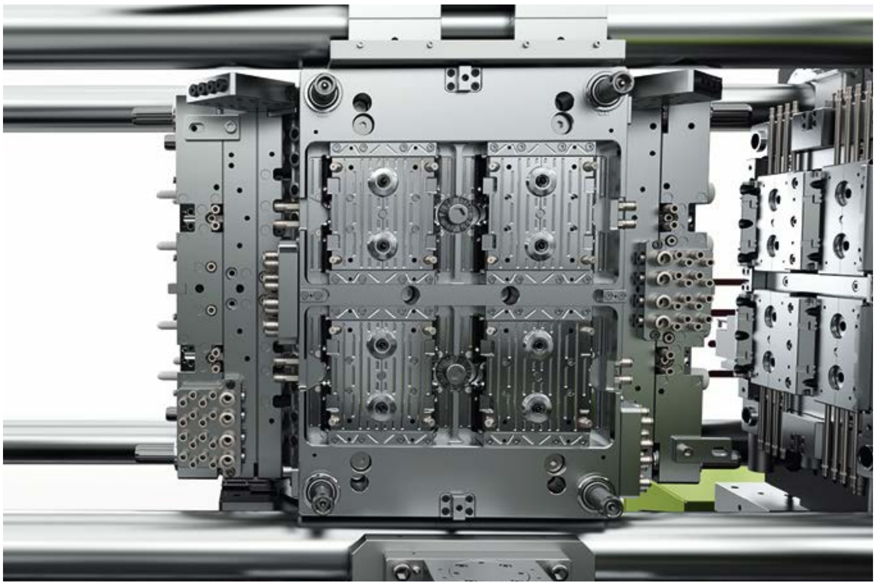

Fig. 10. Injection blow molding allows the economic production of ready-to-use small containers in one step. Based on cube technology, the system can be upscaled to as many as 96 cavities without compromises in cycle time and precision (© Engel)

on the other hand release agents for demolding the parts are not required.

The production line has two reservoirs for the monomer components, which are in a solid state. The two components are independently heated and, in molten form, fed through insulated feed lines to the mold, where the mixing head is located. Even if this all seems complicated, the process is easy to control for an average user in a similar way to the processing of conventional polyamide.

Injection Molding plus Blow Molding

A surprise at this showcase of plastics technology was the renaissance of injection blow molding. Injection blow molds have existed since 1973, and with the continually growing demand for bottles and vials, there have been continuous developments in the corresponding injection blow molding machines. In injection blow molding, a preform is first manufactured and then inflated in a larger cavity. The challenge is to obtain a wall thickness that is as uniform as possible, so that the overall weight of the bottle can be kept as low as possible. In injection blow molding machines, great importance is attached to keeping the preform temperature before inflation as uniform as possible and, in addition, the blowing operation is usually combined with mechanical axial stretching. There is apparently demand again for less specialized injection molding machines with injection blow molds – the reason may lie in the decrease in lot sizes, in which very precise wall thicknesses do not dictate the requirements.

Three systems at the trade show demonstrated the difference in performance and precision compared to the technical sophistication, which will be reflected in the system price. The simplest version was presented by **Dr. Boy** with a 4+4-cavity index rotary mold with horizontal axis of rotation (Schreck Kunststofftechnik). The preforms are manufactured in the upper position and, after rotation through 180°, are inflated in the lower position in the next cycle.

The system presented by **Wittmann Battenfeld** is somewhat more complicated. In this application, with a 2-cavity mold (Grosfilley), preform parts of PP for a 150 ml flacon are injection molded and inflated in the mold. The mold equipped with an index plate consists of three stations: In the first station, the preforms are injection molded, in the second station, they are inflated and in the third station they are ejected by free fall. With an extension of the mold to four stations, the preform part can be overmolded with a second component in order to manufacture attractive multicomponent blown parts.

Engel presented a solution with the system partners **Foboha** and **Alpla Werke Alwin Lehner**. In an 8-cavity cube mold, which was constructed as a proof of principle, small polypropylene containers are produced (**Fig. 10**). The containers were developed by Alpla for a customer in Asia, which until now has packaged its products in glass vessels. By replacing the material, it reduces manufacturing costs as well as packaging weight, and at the same time im- »

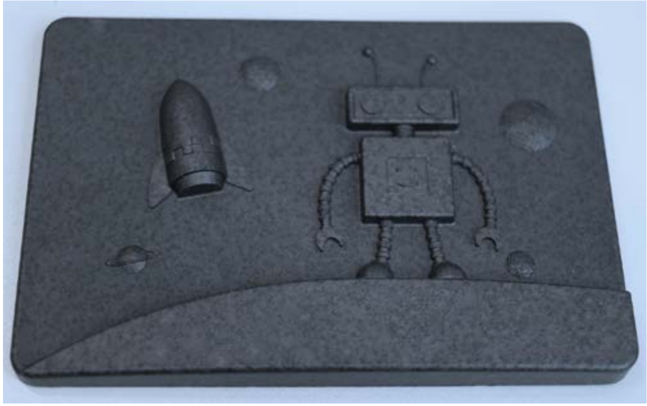

Fig. 11. Demo plate of steam-free foamed polystyrene with inserted magnets (not visible) and a film backfoamed on the reverse side (© Hanser/C. Jaroschek)

proves safety for consumers. For short cycle times, the preforms manufactured in the previous cycle are inflated in the opposite mold position in parallel with the injection molding of the preforms. At the same time, the six-axis robot integrated in the manufacturing cell removes the finished containers from the fourth position. The handling thus takes place in the cycle of the injection blow molding process, and does not prolong the cycle time. The special feature here is an insulating cover in the second station, which ensures uniform heat distribution in the preform. The shot weight is 8 g per container.

A Foam Idyll

Lightweight design can mean different things. On one hand, it can mean parts that can withstand high loads despite a low weight, e.g. fiber composites. However, it can also simply mean parts with very greatly reduced weight. In this regard, **Krallmann**, together with **T. Michel Formenbau**, presented the manufacture of steering wheels from particle foam (EPS, EPP). Here, an injection molded part is overmolded onto a particle foam semifinished part. In conventional particle foam article manufacturing with steam-permeable molds, these semifinished parts can form a firm bond with the part. In this way, very lightweight foam parts can now be produced, which can be very easily fixed in assemblies.

A completely new approach for manufacturing very lightweight parts at the very frontiers of injection molding was presented by **FOX Velution**. In the case of expandable polystyrene (EPS), it has never been doubted that steam is really necessary as an energy medium, for prefoaming the micropellet stock with the pentane blowing agent during manufacturing. In an innovative process, this is now possible without steam in a continuous process, and within just a few seconds. Studies by Neue Materialien Bayreuth GmbH show that the foam beads that are produced have a significantly more fine-celled structure (compared with beads prefoamed conventionally with steam) and the morphology can be influenced independently of the density. This allows the pressure properties of the parts that are subsequently produced to be significantly improved, and their thermal conductivity simultaneously reduced.

For foam molding, too, – irrespective of the type of particle foam used – FOX Velution offers a steam-free alternative that makes use of the variotherm cavities of the Hofmann Innovation Group, which are produced by additive processes. With a temperature control that is both dynamic and precise, foam beads and inserts can be uniformly heated and bonded to form a molded part or sandwich. The process opens up additional potential applications, as was demonstrated at K on samples. Thus, particle foams based on engineering thermoplastics (e.g. E-PBT) can be processed, vapor-impermeable films or reinforcing layers can be back-foamed, sensitive inserts and even uncased electronic components integrated and complex structured or even smooth/gloss surfaces generated "in situ" (**Fig. 11**).

Summary

Injection molding has reached a very high level of maturity. There are fewer amazing innovations than before. That is a good sign, since in the past the enthusiasm for technical sophistication was sometimes overplayed, and these processes and products were ultimately never viable because of their susceptibility to failure. In this regard, we should consider the restrained technical presence particularly of Asian machine manufacturers and additionally compare the global importance of the injection molding machines that are sold annually. It is therefore meaningful to focus on the tried and tested.

But it is also good that there are still visionaries who have the courage to realize entirely innovative technical solutions. ■

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