

# Cutting the Gordian Knot

## *A Start-Up and Five Partners from Industry and Research Are Developing a Steamless Process Chain for Energy-Efficient Processing and In-Situ Functionalization of Particle Foams*

Up to now, the prevailing opinion has been that processing of Styrofoam and similarly cellular materials requires complex processes involving steam. Two engineers have now come up with a dry solution that slashes energy consumption. Not only that, but the duo have also devised a production-ready lightweight engineering approach, namely on how foams can offer new application perspectives the automotive industry is desperately looking for.

**F**or fifty years, the production of molded articles from expanding thermoplastics has entailed the use of steam to expand microbeads filled with blowing agent, drying of the wet foam beads, transporting the now extra-light beads to the mold in the processing station – followed again by steam treatment – baking them to an arbitrary geometry and dehumidifying the whole if necessary. The energy consumption of this process should be obvious to everyone. So why not just reinvent the world?

As the lightweight engineering specialists and manufacturers of insulation materials and packaging among you will already be suspecting, we are talking here about particle foams – materials with a mainly closed cell structure, which have gained a certain amount of fame ever since the brand name Styrofoam entered into general parlance. Since the patenting of expanded polystyrene (EPS) in 1950 as the first representative of its ilk, choosing materials in this area has always been a manageable affair. Expanded polypropylene (EPP) and polyethylene (EPE), like EPS (which is also known as Airpop since May 2014), are characterized by an extremely low density, which can be adjusted down to as low as 10 g/l.

### **98 Percent Air Wrapped in a Plastic Cellular Structure**

The cell structure of the material, 98% of which is trapped air, is also responsible for the outstanding properties, such as low



Steamless-manufactured EPS demonstrator ("Filli Future") with micron-precision surface texturing, PS film decoration on the rear, and gently molded-in functional unit with neodymium magnets, LED array, control board and inductive charging coil (© FOX Velution/B. Girg)

thermal conductivity and high energy absorption. The insulating and shock-absorbing properties are reflected in their standard applications: particle foams serve as thermal building insulation, as transport packaging for electrical appliances and foodstuffs, and are incorporated into sports helmets and other protective helmets. As recently as 2012, BASF launched an expanded thermoplastic polyurethane (E-TPU), which, by virtue of its elasticity, once again marked a clear departure from the mechanical properties of the above-mentioned grades and,

for example, finds application as sole material for sports shoes.

All the advantages above are more than offset by the associated multi-stage processing method in particular and an upper limit of approx. 100°C on service temperatures (with the exception of special structural foams, e.g. polymethacrylimide). Even the very attributes that make polymers so successful in other industries, namely functionalization and decoration, are possible only within narrow limits with these materials, because of the need for steam-based process- »



Up to now, steam has been used for prefoaming of EPS microbeads (left) and fusion of the foamed beads (center, same mass) to yield the EPS molded part (© NMB)



Production-ready lightweight engineering with particle foams: Jörg Vetter and Mirjam Lucht, managing directors of FOX Velution, with sandwich panels produced in a dynamic variothermal foam mold (right)

(© FOX Velution/B. Girg)

## Key Partnerships

Knowledge sharing in return for test equipment for joint success might best describe the collaboration between the developers of FOX Velution and their partner companies. Or, as the two managing directors Mirjam Lucht and Jörg Vetter call it, to borrow from Henry W. Chesbrough: Open Innovation. The participants and their roles:

- Fill Gesellschaft m.b.H., Gurten, Austria: automated specialist production systems
- Krelus AG, Oberentfelden, Switzerland: precision infrared emitters
- Neue Materialien Bayreuth GmbH, Bayreuth, Germany: material and process development in the field of lightweight constructions
- Schenck Process Europe GmbH, Darmstadt, Germany: components for precision weighing and metering
- Werkzeugbau Siegfried Hofmann GmbH, Lichtenfels, Germany: foaming tools with dynamic temperature control

Here, verbal agreements and handshakes are the norm in a form of collaboration that surely only SMEs can enter into.

## Service

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ing. A start-up is now in the process of turning the current laws governing this class of material upside down.

When they are not scurrying from meeting to meeting, as they have done for months, to discuss their innovation with astounded representatives from the automotive industry and polymer production, Mirjam Lucht and Jörg Vetter, the managing directors of Nuremberg-registered FOX Velution GmbH can be found in Lichtenfels, Germany. There, under the roof of Hofmann, a toolmaker for specialist injection molding techniques, the two engineers are running a pilot plant. And they are also demonstrating – wait for it – a completely steamless process chain for the energy-efficient processing of thermoplastic particle foams, from microbeads to molded parts or functionalized sandwiches.

### Initial Skepticism Overcome

In order to turn their idea into a practical series production method, the two founders have gathered about them a number of well-known partners with proven expertise. Foremost among these are the aforementioned Hofmann, and Fill, a specialist machine maker and a stakeholder in FOX Velution. Not by chance, the first two letters in FOX reflect the areas where these three companies are based (F for Franconia and O for Oberösterreich or Upper Austria) while Vetter and Lucht are themselves immortalized in the second part of the name. So what does the X mean? "That stands for cross-border engineering beyond material, process and application boundaries," says Vetter, clearly the brasher member of the pair.

The story began a few years ago, when the manufacturer of a heat-resistant structural foam of high compression strength commissioned Fill to industrialize a laboratory method for energy-efficient, direct forming. Vetter, at that time in the employ of the resourceful Austrian solution provider, and Lucht, actively involved as an external tooling expert, set about devising and evaluating alternative dry processes. As the potential of the application started to emerge, they made a decision: "We need to transfer what we have successfully implemented in this project to other particle foams."

Andreas Fill, managing director of the specialist machine maker, who introduces himself, almost apologetically, as one of the few non-technicians in the company, supported the step to independence in March 2015: "We are reliant on free spirits such as these and we thrive on synergies emanating from different branches of industry. This development has laid the foundation for many products that we still aren't even aware of." Others who professed that they had "tried almost everything" expressed technical reservations about the development. But even these skeptics were won over by the steamless samples exhibited by FOX Velution at the K 2016 international trade show in Düsseldorf, Germany, in October.

### Pouring out Front, Snowing out Back

Anyone familiar with the huge steam reactors which EPS converters use to pre-foam batches of the salt-grain-shaped or rod-like polystyrene micro-beads laden with pentane can scarce believe their eyes in Lichtenfels: "It pours out front and it snows out back," says Jörg Vetter de-

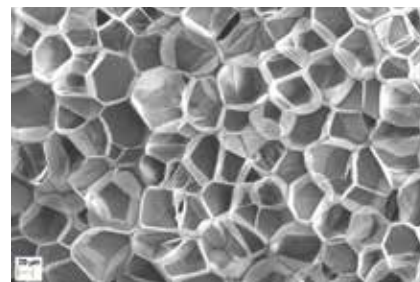
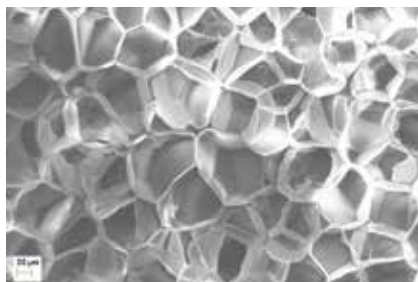
scribing the continuous throughput from the laboratory system. The basic idea is that bulk material metered onto a conveyor belt passes through a specially designed infrared furnace where the microbeads rapidly absorb the heat radiation, quickly assuming the temperature that causes the blowing agent to make the softened matrix to rise like dough. What takes a few minutes by the standard method and often requires downstream conditioning, takes just five to ten seconds and runs under totally dry conditions.

Since January 2016 Neue Materialien Bayreuth GmbH (NMB) and Rygol Dämmstoffe GmbH have been collaborating within the project "IR-PreFoam", based on the initiative and with the support of FOX Velution in order to develop a scientific understanding of the novel prefoaming approach. The project is being funded by the state of Bavaria under the program "New Materials in Bavaria". Current studies on EPS show that the steamless process produces beads with much less size scatter.

This type of prefoaming also positively impacts on the later service properties: "Insulation producers are fighting to gain every last percentage of thermal conductivity and mechanical strength," says Reinhard Pfaller, head of sales at Rygol. "Usually, a higher density means greater compressive strength but has the unintended effect of better heat conduction – and vice versa. The project consortium has been able to slash this Gordian knot and improve both parameters at the same time. FOX Velution and NMB have managed to optimize the morphology of the foam beads without altering the density. The outcome is that, for the same material and bulk density as in the standard process, substantially higher compressive strength values and better insulation have been achieved – under much lower energy consumption. It sounds almost like a side note when Mirjam Lucht says: "Ultimately, we hope to employ less pentane blowing agent."

### Dynamic Tempering via a Narrow-Meshed Runner Network

The step from foamed beads to molded part is already up and running in the Lichtenfels pilot plant, too. For a fuller appreciation of the differences, it is worth



"Half-timbered structure" in SEM: Compared to standard EPS prefoamed with steam (left), foam beads generated on the basis of radiation absorption (right) have a finer cell structure at the same density, which leads to greater stiffness and better insulation properties (© NMB)

recalling the current state of the art. The foam beads are metered into the mold of an automatic molding machine via nozzles. Steam is then admitted and causes the beads to melt and fuse together. The cavity is then cooled with water and the molded part is removed. NMB has calculated that, in extreme cases, up to 99% of the energy input is used for controlling the mold temperature, with only 1% used in some cases to fuse the beads together. FOX Velution has adopted a fundamentally more efficient approach involving dynamic temperature control in a closed system. To this end, it uses 3D-printed molds, which are built up layer by layer from metal powders in the LaserCUSING process. As the molds are being made, a branched runner structure, patented years ago by Hofmann as a surface-tempering system, is carved out just beneath the contoured cavity surface. Managing director Günter Hofmann explains that underneath is a support structure which gives the mold greater rigidity and, due to the presence of air-filled voids, minimizes heat-conduction losses into the base structure – essentially, an insulation structure is co-printed into the insert.

During foaming, hot and cold tempering media flow in alternating fashion through the runner network. "We can extend the working range from 180 to about 300°C by using thermal oil for heating instead of water," explains Stefan Hofmann, also a managing director, adding that heating and cooling rates of up to 30 K/s are attainable. This confers a further advantage for, lo and behold, engineering materials such as E-PBT that can now be used. This is a particle foam which the Bayreuth-based researchers have developed over the last few years and which requires higher temperatures than can be achieved with conventional steam-based



Plastic model of a 3D-printed variothermal mold. The branched runner network of the surface tempering system is shown in blue. This enables the cavity surface to be heated or cooled down to the process temperature within seconds (© Hofmann)

molding. If industry rumors are to be believed, raw materials producers have further foams produced from structural materials locked away in their vaults, which could now be processed by the dry method. Just imagine if expanded polycarbonate or polyamide beads were to become available and all the possibilities they would open up – not just in automotive interiors, but also under the hood.

"Using the highly dynamic tempering, we can achieve cycle times which are comparable to, if not better than, those of the standard steam process," says Mirjam Lucht. But, adds the engineer, with the extra benefit that there is no need for any of the entire infrastructure for producing and transporting the steam and requisite water, not to mention the large sections of storage space for the molded parts. Nonetheless, insulation blocks in storage are not about to disappear entirely, as the otherwise so highly appreciated material properties could prove fateful for the new process in one respect. Foams have an insulating effect, but this process is based on thermal conduction rather than steam convection, and so there are limits on the attainable part thickness. "We can comfortably manage up to 15 mm, and dare to do 25 mm," says Jörg Vetter. »

### Lightweight Engineering in its Purest Form

However, the 48-year-old is quick to qualify this comment: "We're not looking to replace what already exists, more likely to complement it. You see, we have something else up our sleeves." Whereupon he shows the visitor samples which should prove extremely appealing to automotive suppliers: functionalized sandwich systems with stable foam cores, technical textiles or polymer films as well as inserts of all kinds, integrated through the foaming process. "Shear-resistant air sandwiched between two cover layers: this is lightweight engineering in its purest form. And we can functionalize these parts in-situ," he says, enthusiastically.

Up to now, there have been geometric restrictions on the production of such composites for structural or decorative applications because, especially in the case of thin-walled, largely closed structures, "most reinforcing or decorative layers are not steam-permeable," adds his colleague. Not to mention the usual marks that steam nozzles leave on areas of the molded surface. There is one area in which seamless foam-molding can even outperform injection molding and that is the integration of electronics or sensor technology. Here, the chances of implementing new ideas are good, due to the comparatively moderate processing temperature and pressures as well as the absence of melt-flow-induced shear stress.

The first fruits of this work are to be seen in a demonstrator part proving precision-molded tool contours, as well as integrated magnetic holders and embedded signaling unit, and showing the technology messenger "Filli Future" of the Austrian co-stakeholder. Mirjam Lucht explains: "We don't even have to encapsu-

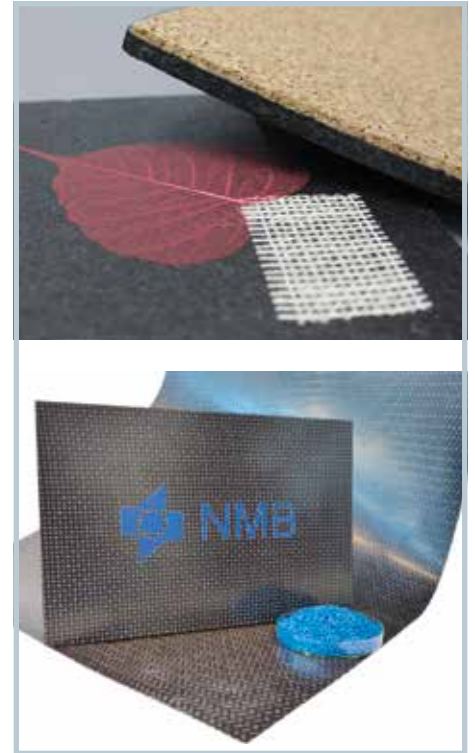
late the electronics. They're foamed naked, so to speak, without suffering any damage."

### Embossed, Reinforced and Decorated

All accomplished tests have been successful, no matter whether the core material was an EPS or an EPP, and the cover layer was a printed film, cork board, a linen fabric or a glass-fiber-reinforced PP laminate with countersunk logo openings. Moreover, in-situ structures can also be embossed into surfaces as desired. The one-step process is thus shorter than standard composite processes that required a second step for "bonding" the foam cores to reinforcing layers, e.g. in compression RTM or by wet-pressing.

So far, though, the duo have limited themselves to DIN A4 format. Even so, the variothermal mold can reproduce different panel thicknesses with its dipping edge. The partners believe that in principle there are no limitations, whether in (three-dimensional) complexity or in size, with the exception of the aforementioned part thickness. Now it might be interjected that the mold dimensions are limited by the build envelope of today's laser sintering systems. Günter Hofmann begs to differ: "These systems will surely get bigger in the future. Anyway, we are currently studying a concept for joining additively manufactured tool parts together to form a large whole."

In any event, the partners are tackling the issue and have their sights on the market. For example, NMB in Bayreuth recently commissioned a line built by Fill for radiation-induced prefoaming of propellant-laden microbeads. The line features an integrated, highly accurate metering system from Schenck Process as well as special IR emitters from Krelus and has a nominal capacity of 100 kg/h.



Natural decorative materials can be back-foamed just as readily without steam as high-strength sandwich structures made from PP-GF laminates (here: with a milled logo and EPP hybrid foam core) © FOX Velution, NMB

### Foam on Wheels?

There are also great plans for Lichtenfels. Within the year, the small pilot plant is to give way to a ramp-up factory, which will manufacture customer parts on an industrial scale under a high degree of automation. "OEMs and suppliers naturally want to see more than handy panels and to know what a real production plant costs and delivers," says Vetter. The idea here is very much to extend the application focus from automotive interiors to supporting structures in the near future.

The development consortium harbors no doubts that there is a need for this. Quotas for electric vehicles which will be introduced in China from 2018 onwards, a further tightening of CO<sub>2</sub> legislation in Europe, the unacceptable discrepancy between exhaust gas values obtained on the test-rig and in the real world – the industry urgently needs solutions for these issues. The founders of FOX Velution see it this way: "Cars need to weigh one-third less. We maintain that this can only be done with foam." ■

Dr. Clemens Doriath, editor

Tunnel oven for continuous radiation-induced prefoaming of expandable microbeads in the pilot plant of Neue Materialien Bayreuth © NMB

