While Processing Trials Proved Highly Successful, an Intuitive Feeling Is Required

Processing Bioplastics in Hot Runners

The Cologne-based compounder Bio-Fed and Günther Heisskanaltechnik GmbH of Frankenberg in Hessen, Germany, have performed various trials, which show that even supposedly sensitive bioplastics can be reliably processed in hot runner molds.

Biodegradable polymers that are manufactured from biomass are gaining in importance for formulating plastic compounds. Not least, they permit sustainable material designs to be realized. Nevertheless, their shear sensitivity poses a challenge for processing, in particular where thin-walled parts and slender hot runners are concerned.

One example of this is polyhydroxyalkanoates (PHAs), which are obtained through the microbial fermentation of carbohydrates and fats [1]. Under special conditions, they can be readily degraded by microorganisms at room temperature. The generic term PHA [2], covers a whole group of polymers with different structures (**Fig. 1**) and a wide bandwidth of mechanical properties. Annual production of these biopolyesters is predicted to increase from the current 50,000 t to 250,000 t by 2025 [3]. The low CO_2 footprint and outstanding biodegradability of PHAs qualify them as ideal components for bioplastics, which perform their function as replacements for fossil raw materials in various applications [4].

Processing of PHA-Based Compounds

To generate empirical values in the processing of such materials, Günther Heisskanaltechnik has performed trials on the grades M·Vera GP1012 (with natural fibers) and GP 1045 supplied by Bio-Fed. Both are home-compostable, PHA-based compounds consisting entirely of renewable raw materials that are high-temperature resistant (HDT>100 °C). They are also suitable for food contact.

The M·Vera compounds can be processed on conventional injection molding machines with a universal screw configuration. They have already been successfully used for various commercial applications, such as packaging or cutlery. However, special conditions must be observed: PHA compounds require moderate processing temperatures, and the melt temperature must not exceed 165 °C.

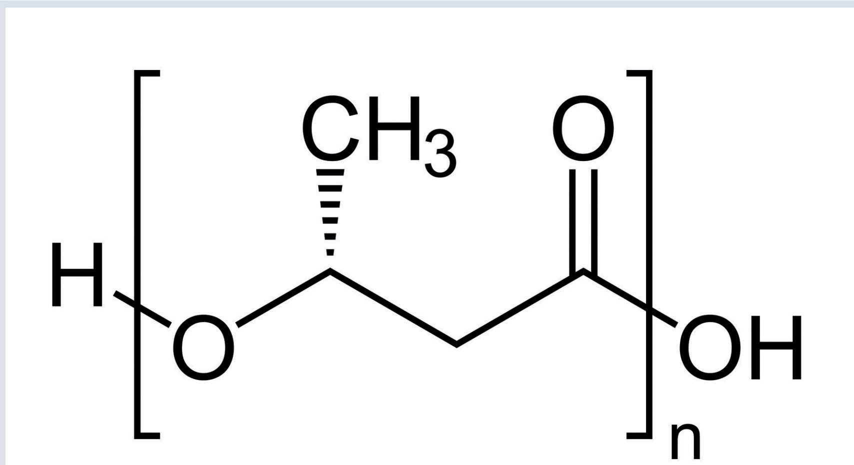

Fig. 1. Chemical structure of poly-(R)-3-hydroxybutyrate (P3HB), a polyhydroxyalkanoate.
Source: Public Domain

The low processing temperatures increase the melt viscosity and thereby the flow resistance, and higher injection pressures may therefore be necessary compared to standard thermoplastics. In addition, it is important to avoid high shear forces and long residence times that can lead to excess heat development and possible polymer degradation, in particular for thin-walled applications with conventional cold runners. In the mold design, nozzles, runners and gates with small diameters should be avoided, since they hinder the melt flow and increase the shear heat [5].

A rheometer analysis (**Fig. 2**) shows the influence of different melt temperatures on the viscosity of M·Vera GP1012. A viscosity drop of the material can already be observed at between 140 and 150 °C, indicating a smaller processing window compared with conventional polymers.

During the cooling phase, PHAs crystallize fastest at 40 °C mold temperature, so that temperature control is important for an efficient cycle. The mechanical properties are not dependent on the temperature of the mold (**Table 1**).

The main goal of the cooperation between Bio-Fed and Günther Heisskanaltechnik is to analyze the flow behavior and processing stability of newly developed PHA compounds in two state-of-the-art hot runner types. This is intended to broaden the application range of these bioplastics, in particular where precision parts with short cycle times are to be manufactured.

Special Hot Runner Nozzles Help with Processing

Experience shows that, for processing the biomaterials, hot runner systems with an adequate temperature behavior should be used in order to avoid thermal damage. In order to ensure this temperature behavior, the hot runner system should be designed according to thermal and rheological principles.

The necessary temperature behavior in the hot runner is influenced, for example, by good thermal separation between the temperature-controlled mold and the heated hot runner nozzle, The hot runner nozzles from Günther Heisskanaltechnik achieve this thermal separation by means of a two-part shaft comprised of a titanium alloy with a thermal conductivity of about 7 W/(m·K) as well as of steel. An air gap between the nozzle shaft and heating produces an additional thermal separation. The use of BlueFlow heating (**Info box p. 55**) permits targeted distribution of the heating power. For example, over 50 % of the entire heating power is concentrated at the front region of the nozzle (tip). This ensures that an adequate amount of thermal energy is conducted into the tip. Since there is no heat dissipation in the central region of the nozzle, the heating power is significantly reduced in this region in order to avoid overheating (**Fig. 3a**).

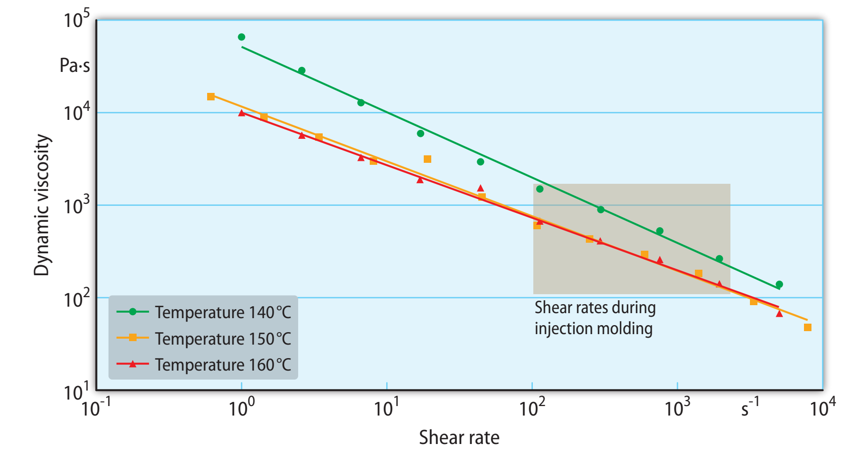

Fig. 2. Capillary rheometer analysis of M·Vera GP1012 shearing vs. viscosity sweep at various temperatures. Source: Bio-Fed; graphic: © Hanser

Testing	Unit	Mold temperature 40 °C	Mold temperature 60 °C	Mold temperature 90 °C
Elastic modulus (5 mm/min)	MPa	2330	2270	2300
Elongation at yield (5 mm/min)	%	3.1	3.3	2.9
Yield strength	MPa	18.5	18.3	18.2
Tensile strength	MPa	18.5	18.3	18.4
Elongation at break	%	4	4.8	5
Strength at break	MPa	17.8	17.5	17
Charpy notch impact strength 23 °C	kJ/m²	12.9	14.1	11.2

Table 1. Mechanical properties of M·Vera GP1012 at various mold temperatures. Source: Bio-Fed

Many of the hot runner nozzles available on the market are centered in the cavity insert either directly or via a titanium ring. This metal connection from steel to steel in the region of the gating point results in very good thermal conduction. Since heat obviously always flows from the hot to the cold body, a high heat loss in the hot runner nozzle can be expected (**Fig. 3b**). The result is that the actual temperature in the hot runner nozzle is in some cases significantly »

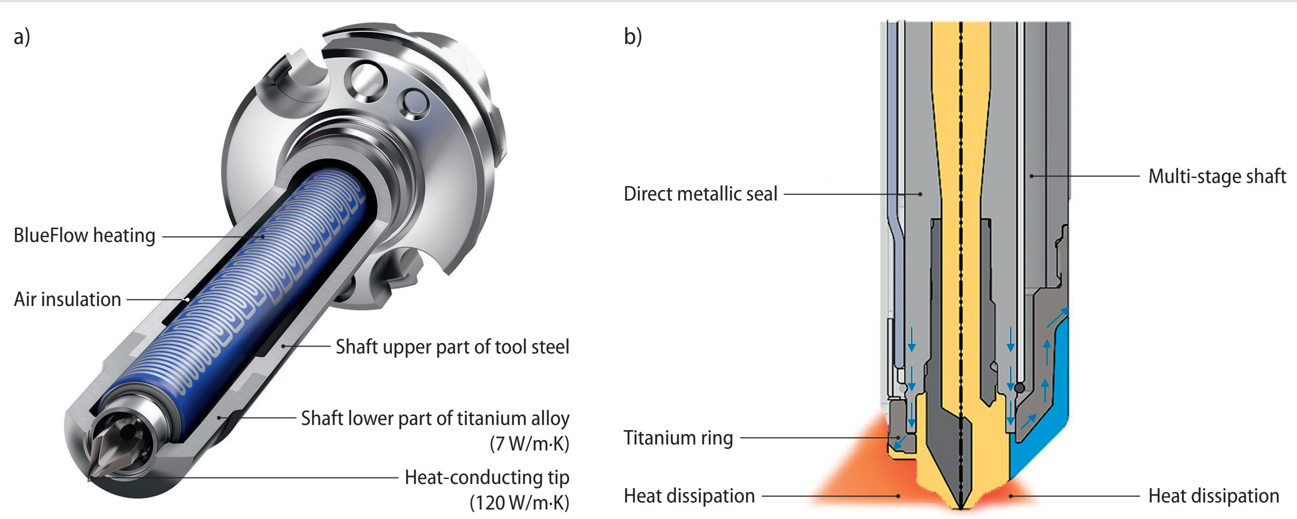

Fig. 3. Hot runner nozzle with tip and BlueFlow heating (left) and heat dissipation (right) by the metal connection of the nozzle to the mold insert.

Fig. 4. Interchangeable inserts for various test samples can be installed in the two-cavity trial mold. © Günther Heisskanaltechnik

above that displayed. As a result, sensitive polymers – including additives – may be thermally damaged.

In the case of the nozzle with a two-part shaft, there is a significantly lower heat loss, and consequently a more homogeneous temperature profile without huge temperature excesses. As a result, thermally sensitive plastics such as PHA can be readily processed.

Test Mold for Different Trial Bodies

The processing trials performed in the pilot plant of Günther Heisskanaltechnik are intended to show to what extent the selected M·Vera grades can be processed with different hot runner systems (open vs. valve gate). The following items were assessed during the performance of the trials:

- Determination of parameters for a stable process.
- Opening behavior of the gate points/filling study.
- Maximum holding pressure time of valve gate.
- Start-up behavior after simulated process interruption.
- Evidence of process stability over a defined period.

For the trials, a two-cavity trial mold from Günther Heisskanaltechnik (**Fig. 4**) was operated on an electrical injection molding machine (type: Allrounder 520A, 1500–400; manufacturer: Arburg). The mold is constructed so that exchangeable inserts with various designs of test specimens can be used at the moving mold half. The fixed mold half can optionally have open nozzles with a tip or valve gates.

Trials with Open Hot Runner Nozzle

The trials with an open hot runner were performed using two type 6SHF80 nozzles with BlueFlow heating (**Fig. 3**), in which the heat is conducted into the gating point via the tip, which is made of a highly conductive metal. This results in a largely uniform opening behavior at the gates in conjunction with a high-quality gating point. In this case, a disk-like sample body (**Fig. 5**) was measured using a 1.2 mm diameter gating point.

The PHA blends were processed with a process temperature of 150 °C (injection unit and hot runner) and a mold temperature of 40 °C. The process here was found to be stable without pressure fluctuations. The temperature of the hot runner nozzles was gradually reduced to 135 °C without process fluctuations occurring.

A filling study could be generated with the same nozzle temperatures. The restart after a simulated process interruption of 15 minutes was possible without restriction. The quality of the gating point is assessed as good for a nozzle with tip. In the type GP1012, the natural fibers act as nucleation agents: Compared to GP1045, the sample bodies are demolded with a cooling time that is 5 s shorter. With the optimized parameters, the PHA blends were processed in a stable process over a period of one hour.

Trials with Valve-Gate Nozzles

The trials with the valve-gate system were performed using two type 8NHT2–80LA nozzles. For a valve-gate system, the opening behavior is even more precise and the quality of the gating point is best in terms of optical and tactile properties. In the needle guide type LA used here (**Fig. 6**), the gating point is integrated in the needle guide and thus shapes the contour. The

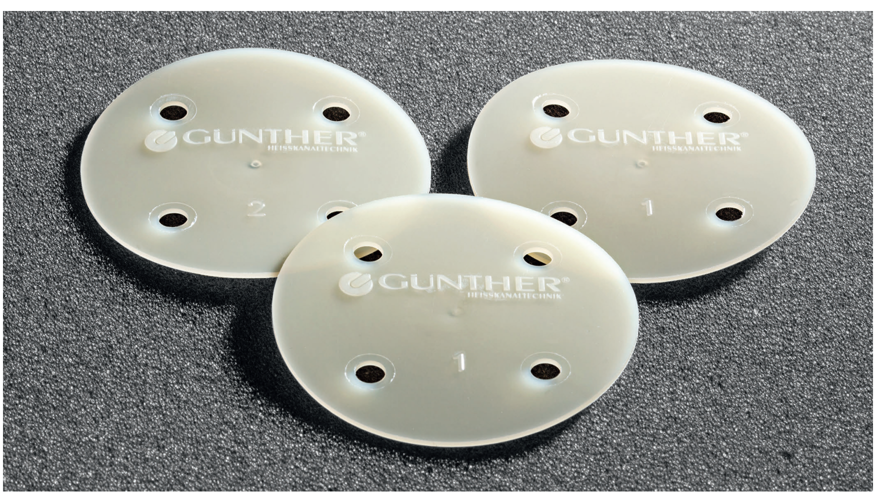

Fig. 5. Shot-weight 3 g, diameter 60 mm, wall thickness 1 mm; the "disk" test sample. © Günther Heisskanaltechnik

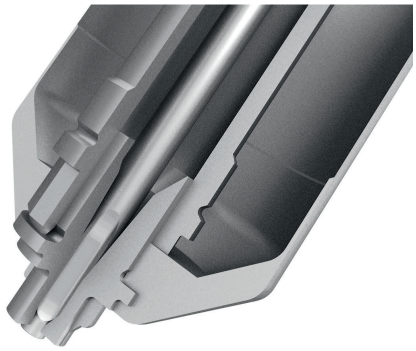

Fig. 6. Type LA needle guide, made of a wear-resistant steel. © Günther Heisskanaltechnik

needle guide consists of a powder-metallurgical steel, characterized by high wear resistance. The needle guide is positioned floating in the nozzle and if needed can be easily exchanged without reworking the mold insert.

Valve needles with a gating point of 2.0 mm are used, which are moved by means of a pneumatic individual valve with a maximum valve closing force of 800 N. The chosen rod-shaped test sample (**Fig. 7**) has a wall thickness of 2 mm and a flow path length of approx. 90 mm.

Both M·Vera grades GP1045 and GP1012 could be processed in a stable process at a hot runner temperature of 150 °C and a mold temperature of 40 °C. As is generally the case with valve systems, the holding pressure time for the two PHA grades is limited due to the solidification behavior of the melt during the holding pressure phase. With a holding pressure time that is too long, overloading of the article, or flash formation, may occur during closing of the valves.

After a simulated process interruption of 15 minutes, the process could be restarted without restrictions for both material types. The first parts showed a slight discoloration.

Both GP1045 and GP1012 could be readily demolded after a cooling time of 3 s. However, impressions or deformations due to the ejector pins can be seen up to a cooling time of 6 s. To be able to demold the article with a wall thickness of approx. 2 mm without deformation or impressions, the cooling time should be over 6 s. In addition, it is advisable to provide temperature control near the gate, which can be separately operated. The injection pressure profile does not show any anomalies and the documentation of the process capability with a running time of one hour shows that the process is stable.

Summary

The tests show that, both PHA grades can be equally well processed with the standard hot runner nozzles from Günter Heisskanaltechnik as open (tip) and valve gate alternatives. With the use of the above-described hot runner nozzles, stable and gentle processing of the M·Vera grades by Bio-Fed is possible within the specifications. ■

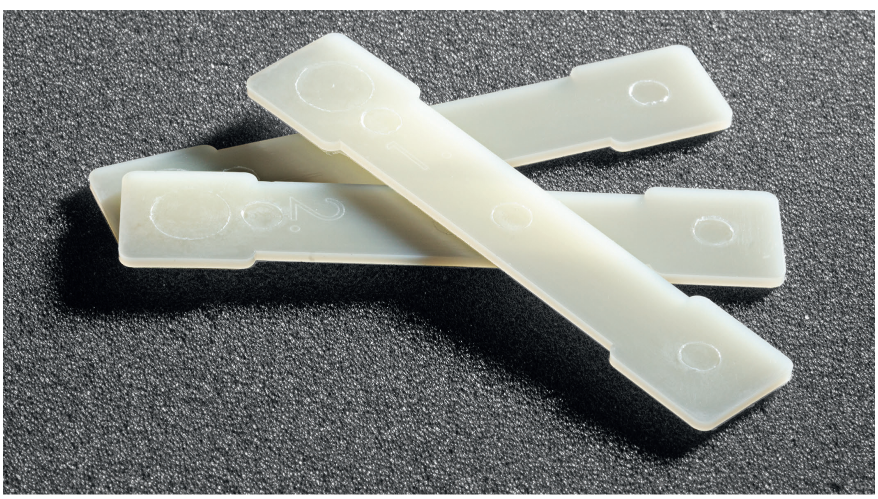

Fig. 7. Shot-weight 4 g, flow-path length 90 mm, wall thickness 2 mm; the "rod" test sample.

© Günther Heisskanaltechnik

Thick Film Heater

The BlueFlow hot runner technology uses heating elements based on thick-film technology. The dielectric layers and the heating elements are applied by screen printing under cleanroom conditions. This offers the following advantages:

- Precise and homogeneous power distribution across the entire nozzle length
- Avoidance of temperature spikes in the melt-guiding material tube
- High power concentration in the front nozzle area
- Fast thermal reaction, resulting in lower energy consumption and shorter cycle times
- Intricate structure with low exterior diameter, resulting in lower gauge diameters and greater degrees of freedom for the temperature profile and direct gating

Info

Text

Dipl.-Ing. Jörg Essinger is Head of Applications Technology & Service at Günther Heisskanaltechnik GmbH, Frankenberg, Germany; essinger@guenther-heisskanal.de

Dr.-Ing. Alejandro Puentes is Development Application Manager at Bio-Fed, a subsidiary of Akro-Plastic GmbH in Cologne, Germany; lejandro.puentes@bio-fed.com

Dr. Inno Gaul is R&D Director of Bio-Fed; inno.gaul@bio-fed.com

Service

Further information about the mold and hot runner manufacturers:
bio-fed.com
www.guenther-hotrunner.com

References & Digital Version

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

German Version

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