Properly Foamed with IML

How Does the Addition of Blowing Agent Affect Adhesion and Molded Part Properties?

Thermoplastic foam injection molding enables lower melt viscosity due to the addition of blowing agent, which is also attractive for the production of thin-walled packaging. Since injection molded packaging is often decorated through in-mold-labeling, it is important to understand how the blowing agent affects adhesion between the film and the molded part to avoid bubble formation at the interface.

Selecting the right IML film is critical for visually appealing molded parts © IKV

Foam injection molding is a well-established special injection molding process and is used primarily in the automotive industry and for white goods [1, 2]. The process allows both molded part weight and warpage to be reduced. The blowing agent also leads to a lower melt viscosity and makes it possible to realize higher flow path/wall thickness ratios and lower processing pressures [3–5].

This point is of particular interest in the packaging industry, since flow path/wall thickness ratios of 200 to 400 with wall thicknesses of 0.2 to 0.6 mm are the norm for injection molded packaging [6]. Since material costs in the packaging industry account for up to 70 % of unit costs, material savings make sense not only from an ecological but also from an economic point of view. The incorporation of a blowing agent enables the use of materials with higher viscosity, which have better mechanical properties compared to easy-flowing materials [7]. In low-viscosity polypropylene grades for packaging applications, the Young's modulus and especially the impact behavior decrease with viscosity [8].

Injection molded packaging is predominantly decorated by the IML (in-mold labeling) process [9]. Use is made of printed films that have a multilayer structure to meet the requirements for barrier, optical and haptic properties. Of interest for adhesion are the surface properties on the side facing the molded part. This inner side of the films is usually pre-treated to enable a good bond to the molded part.

In addition, the material in the core of the film is of interest, since EVOH (ethylene vinyl alcohol copolymer) layers are used here in addition to oriented polypropylene (OPP). These film layers have low oxygen permeability and have proven successful for perishable foods.

It is known from foamed technical components that subsequent outgassing of the blowing agent can lead to bubble formation under the film [10]. Therefore, the combination of foam injection molding with IML films is challenging. Analyzing the influence of the blowing agent on the composite is necessary to understand causes of bubble formation and to harness the potential of foam injection molding in the packaging segment.

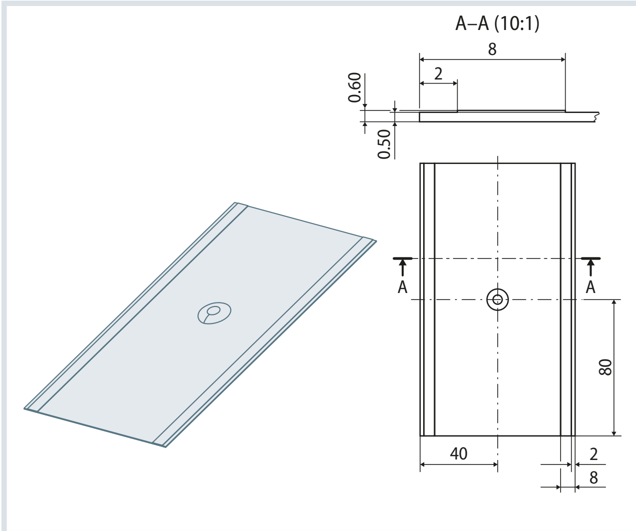

Fig. 1. Sheet geometry with flow aids was used for the tests Source: IKV; graphic: © Hanser

Lower Injection Pressure due to the Addition of Blowing Agent and IML

The Institute for Plastics Processing (IKV) at RWTH Aachen University, Germany, has investigated the effect of a blowing agent on the film composite for three polypropylene grades (**Table 1**). For this purpose, the MuCell process (supplier: Trexel GmbH, Gummersbach, Germany) was used on an Allrounder 520 A 1500–400 injection molding machine (manufacturer: Arburg GmbH + Co KG, Lossburg, Germany). After preliminary investigations, it was decided to charge the melt with 1 % nitrogen. This allows a viscosity reduction with simultaneous high reproducibility, despite the short dosing times.

A plate with the dimensions 160 x 80 x 0.5 mm (**Fig. 1**) served as the test object. Since there is no point symmetry in the molded part, there is a higher pressure on the shorter sides of the plate (compared to the longer sides), which is homogenized by a flow aid. To design the flow aid, the filling process was simulated.

The tests were carried out with several film types having different optical and haptic properties (**Table 2**). The films were inserted into the cavity by a W822–1396 handling unit (manufacturer: Wittmann Kunststoffgeräte GmbH, Vienna, Austria) and fixed by electrostatic charging.

Reference tests without IML show, as expected, that the injection pressure decreases due to the propellant loading compared to compact injection molding. The highest pressure decrease (up to 18 %) is measured with PHC27 (**Fig. 2**), with the percentage pressure decrease rising with injection speed. The IML tests are performed for PHC27 at the same process parameters as in the central point highlighted in gray. By inserting the IML films, the pressure requirement decreases a little further by up to 31 bar when using the 55 µm thick solid white BOPP2 film (**Fig. 3**). The reason for the lower injection pressure when using a film inserter is the higher contact temperature due to the film. However, no correlation can be established between film thickness and pressure requirement.

Manufacturer	Designation	MFR (230 °C, 2.16 kg)
LyondellBasell	Moplen EP600V	100 g/10 min
Sabic	Sabic PP FPC45	45 g/10 min
Sabic	Sabic PP PHC27	14 g/10 min

Table 1. The following polypropylene grades were processed in the trials using the MuCell process Source: IKV

Designation	Description	Thickness [µm]
White voided BOPP	White, matt, soft-touch	60
Solid white BOPP 1	White, one side glossy	70
Solid white BOPP 2	White, both sides glossy	50
Transparent solid BOPP	Transparent, glossy	55
White CPP film	White, one side glossy	65
O2 BAR	Oxygen barrier	65

Table 2. IML films with different optical and haptic properties and thicknesses were selected for the back-molding tests Source: IKV

Influence on Film Adhesion and Optical Appearance

Depending on the film used, different surface qualities are achieved. In the case of the white voided BOPP, solid white BOPP 1 and 2 and transparent solid BOPP types, the test specimens have a uniform surface without raised structures. However, with the white CPP, O2 Bar and reverse printed films, visible bubbles form, which is not acceptable for packaging applications. A possible explanation for this, according to the manufacturer, is the different layer structure compared to the other films. The O2 BAR is the only film with an EVOH core. At 0.7 $cm^3/(m^2 \cdot day \cdot bar)$ (23 °C – 50 % RH), the oxygen permeability of the film is lower by a factor of 400 to 1100 than that of the other films. Therefore, the permeability is probably also limited for the nitrogen blowing agent. In the tests, the bubbles are formed after the mold opens, as in a post-blow, and continue to grow for several minutes.

The permeability of the white CPP film and reverse printed films, 470 and 889 $cm^3/(m^2 \cdot day \cdot bar)$, respectively, is in the same range as that of the other films. Consequently, bubble formation as a result of the low permeability of the films can be excluded. On the other hand, »

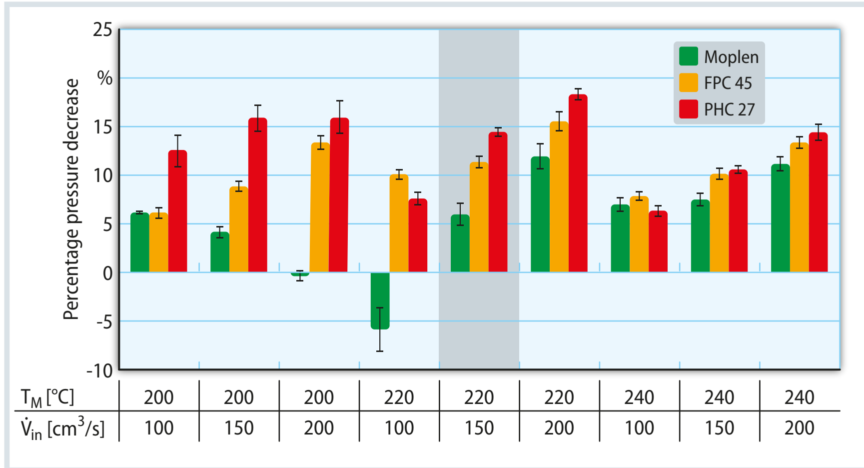

Fig. 2. The injection pressure is reduced by the blowing agent Source: IKV; graphic: © Hanser

it can be explained by the surface condition on the bonded side: the reverse printed film is printed on the inner side, which weakens the bond between the film and the molded part.

The lower adhesion strength allows the blowing agent to form bubbles at the interface between the mating parts. In the case of the white CPP film, little information is available on the surface treatment. Since the permeability of the film is high, a relationship between the bubble formation and the surface treatment of the film is assumed to be the reason for the bubble formation.

In addition to the decoration of the IML component, the achievable adhesion strength between film and packaging is also relevant. Using the LumiFrac 200 adhesion tester (manufacturer: LUM GmbH, Berlin, Germany), the bond strength was determined for all films and material combinations. In the case of the bubble-free IML molded parts, only individual film layers or the printing on the films become detached from the molded part. The film adhesion can therefore be tested purely optically with the samples available. Thus, sufficient bond strength can be recorded for the bubble-free product combinations, irrespective of the film and material.

Influence of Blowing Agent on Molded Part Warpage

Molding warpage is another important quality characteristic. To analyze the warpage, the test specimens are photographed in profile and the images are then evaluated using the open source

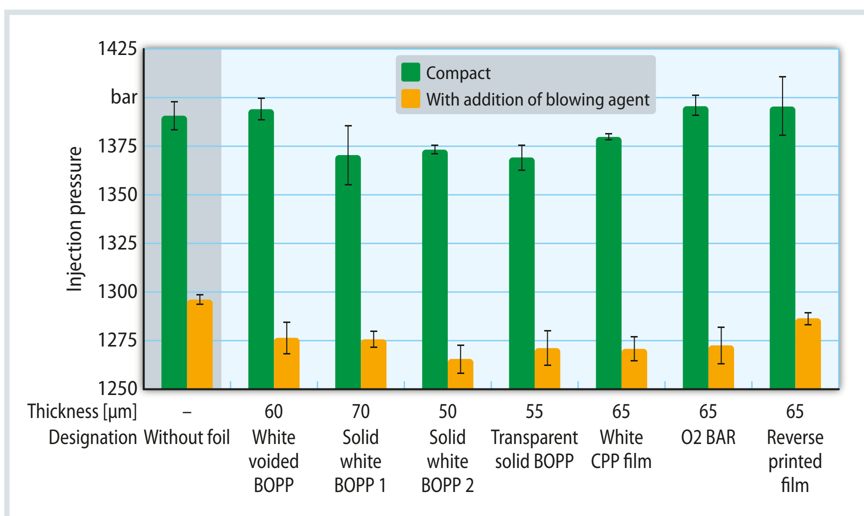

Fig. 3. Influence of different IML films on the injection pressure with and without blowing agent for PHC27 and a 0.5 mm thick sheet Source: IKV; graphic: © Hanser

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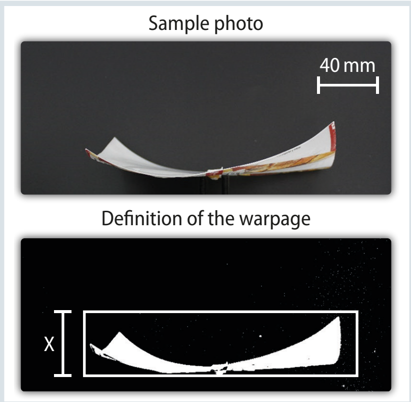

Fig. 4. Warpage X is defined as the distance between the highest and the lowest point in the side view of the sheet Source: IKV; graphic: © Hanser

Foam Injection Molding in Thin-Wall Applications

To fully exploit the potential of thermoplastic foam molding, users must be aware of the challenges and deal with them in a targeted manner.

Potentials:

- The addition of blowing agent to the melt lowers the glass transition temperature and viscosity.
- The lower viscosity allows either longer flow paths or a reduction in melt temperature or injection pressure.
- The blowing agent acts in the same way as the holding pressure on the process side, thus reducing cycle time and allowing thicker areas at the end of the flow path end to be filled without sink marks.

Challenges:

- The addition of blowing agent to the melt reduces the plasticizing performance of the machine.
- The introduction of blowing agent increases the complexity of the process.
- Due to the change in rheological properties, material data may be less meaningful for part design.
- For packaging, IML can lead to bubble formation. However, with appropriate film selection and packaging, greater design freedom is achieved.

program ImageJ. A macro automatically detects the molded part in front of the background and surrounds it with a rectangle. The height of this rectangle is referred to as the warpage in the following (**Fig. 4**).

Contrary to the experience with foamed moldings, warpage increases in the examined sheets without film due to the addition of blowing agent (**Fig. 5**). In this case, warpage can be reduced at larger wall thicknesses by foaming during foam injection molding [4]. At the low wall thickness, an extremely fine-cell foam structure is formed due to the high cooling rate because the cells have only a short time to expand, so the warpage cannot be reduced.

The influence of the blowing agent on the warpage is small compared to the influence of the films (**Fig. 5**). The reason for the higher warpage with film inserts is the changed cooling conditions on one side of the molded part. Warpage is not significantly dependent on the film thickness, but on the type of film. Only in the case of white voided BOPP, a soft-touch film, can lower warpage be achieved with the incorporation of a blowing agent compared with the reference without film. This is probably due to the special layer structure that creates the soft-touch effect. The film is advertised by the manufacturer as a warp-free decorative film. The transparent solid BOPP film leads to the greatest molding warpage despite the low thickness of 55 µm.

Conclusion

Foam injection molding showed some advantages over conventional processing in the practical trials. Therefore, the use of this process in some packaging applications is reasonable and its economic viability should be examined as an alternative when designing new packaging. The lower processing pressures allow wall thickness reduction compared to the compact reference. In further tests with the plate, the wall thickness was reduced from 0.25 mm to 0.20 mm at the same injection pressure.

With a suitable film, the decoration of foamed packaging in the IML process is possible without the formation of bubbles between the film and the molded part. In addition to oxygen permeability, the surface treatment of the film is probably also decisive, both of which are often specified by the manufacturer.

In the case of the films used in the tests, the bond between the film layers is lower than the adhesion of the film to the molded part in the case of a bubble-free bond. Therefore, as a further indication of the suitability of the film, the bond can be checked visually.

The warpage of the molded parts also depends strongly on the film used, so film selection is also important for warpage optimization. Other possible influences on injection pressure and resulting part warpage, such as thermal conductivity or specific film properties, have yet to be analyzed. ■

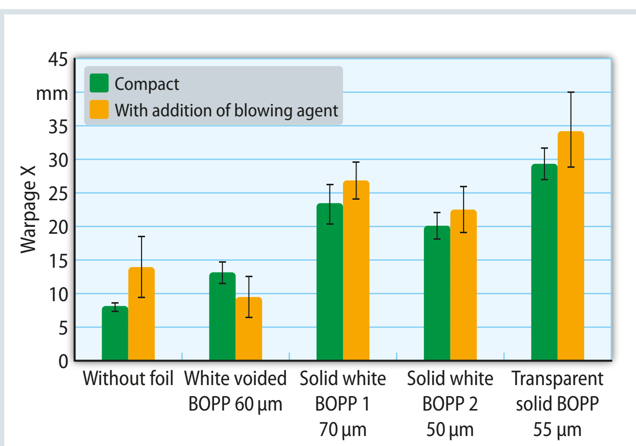

Fig. 5. Influence of IML film on the molding warpage of a 0.5 mm thick sheet of PHC27 Source: IKV; graphic: © Hanser