Resisting the Pressure

More Resource-Efficient Materials for Thermoforming

Contrary to the current perception, plastics, as a component of packaging materials, often represent the most environmentally sound option. The plastics industry is currently undergoing a transformation, shifting the focus onto the realization of closed material loops as well as reducing the resource input with highly efficient materials.

To allow the saving potential of the formulations for thermoforming films to be tested under laboratory conditions, it was determined at what compression resistance the cups manufactured from the semi-finished products resist deformation © IKT

Thanks to suitably designed packaging, foods can be efficiently protected without significantly increasing the ecological footprint of a product [1]. Flexible plastic packaging is superior to other materials, such as glass and cardboard, in many ways. While 1 kg of plastic can be used to package some 56 kg of a product, cardboard can only package a half, and glass only 1/30 of this amount [2]. In the last 20 years, in Germany alone, changes in consumer behavior have meant that the amount of packaged consumer goods transported in a heavy goods vehicle has increased by about half, while transport distances have also risen [3]. This makes an additional saving of packaging weight a significant instrument for conserving resources.

Current Practice

An important and very versatile representative of plastics in the field of packaging materials is polypropylene (PP), which accounts for a high proportion of approx. 19% of the European plastics market [4]. If only the flexible packaging sector is considered, this figure even rises to 30% [5]. This is mainly the result of the material's properties, such as its very good chemical resistance, low water-vapor permeability and higher mechanical strength compared to polyethylene [6]. The disadvantage is the narrow processing window [7] that is typical of semi-crystalline polymers, so that amorphous polymers, such as polystyrene are often preferred, especially for thermoforming.

The aim of a joint research project between the Institut für Kunststofftechnik (IKT), University of Stuttgart, Germany, and Constab Polyolefin Additives GmbH, Rüthen, Germany, is to improve the property profile of polypropylene for the production of thermoformable semi-finished film products by using fully miscible blend components. First, the thermal energy requirement for processing is to be reduced, and the processing temperature window enlarged. Second, the mechanical performance of the product is to be improved, so that the wall thickness of the packaging and therefore the necessary material con-

Fig. 1. Film take-off by means of a calendering unit © IKT

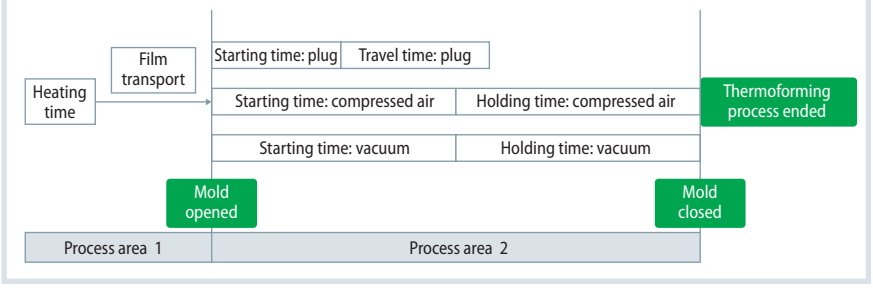

Fig. 2. Process flow during thermoforming © Source: IKT, graphic: © Hanser

sumption is reduced. It should be possible to process the developed blends by conventional extrusion as a drop-in solution.

Manufacturing Thermoformable Semifinished Film Products

To further highlight the positive properties of PP, the project partner Constab first manufactured masterbatches on a pilot scale. These comprised blend materials based on PP in each case, as well as a blend component that is fully miscible with the base material. From the blends that resulted, a screening was carried out jointly between the project partners IKT and Constab to define a large range of different film formulations. **Table 1** shows a selection of formulations that have proved particularly useful.

The formulations were extruded into 300 mm-wide films with thicknesses 1 mm, 0.8 mm and 0.7 mm. The masterbatches were fed together with the basic material via the main hopper of the extruder (PP homopolymer: MFI 3 @230 °C/2.16 kg, laboratory extruder with a screw diameter of 30 mm and an L/D ratio of 25; manufacturer: Collin Lab & Pilot Solutions GmbH, Maitenbeth, Germany). The temperature profile at the extruder was chosen constant for all trials; the temperatures at the cylinder and die varied between 190 °C and 230 °C. The slit die with a width of 300 mm has a coat-hanger die, which is also controlled to a die temperature of 230 °C via four separate heating zones. The output melt film is then brought to the desired thickness with a calendering unit (type 136/350, manufacturer: Collin) and cooled until it was dimensionally stable. The roller unit (**Fig. 1**) consists of a chill roll (144 mm diameter), a cooling roll (72 mm), as well as a smoothing roll (72 mm). During processing, the most important machine parameters, such as motor current, die pressure and throughput, were logged and used to determine the specific energy consumption for processing the different film formulations.

After the film extrusion, the thermal properties were investigated by means of dynamic differential scanning calori- »

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Service

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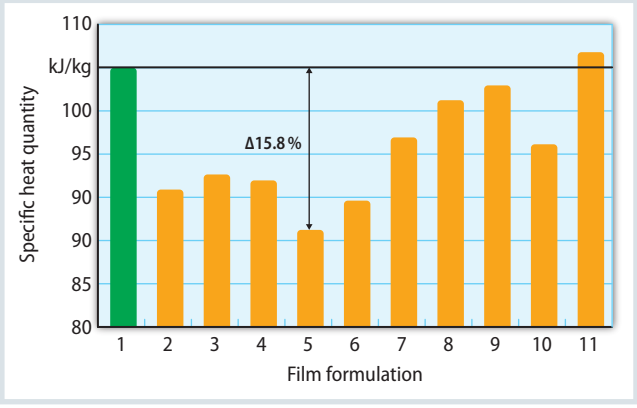

Fig. 3. Compared to the reference [1], most modified formulations have a reduced melt enthalpy Source: IKT, graphic: © Hanser

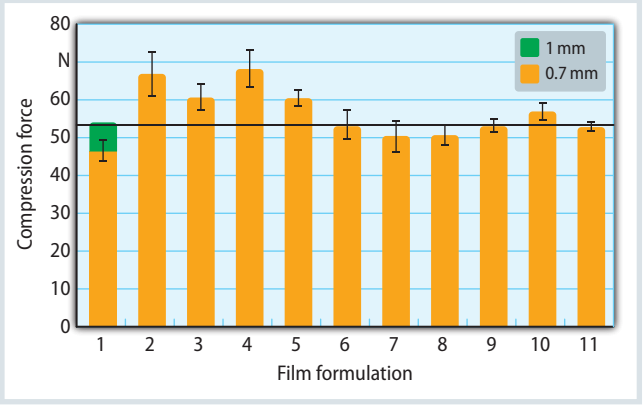

Fig. 4. Increasing the compression resistance by addition of masterbatches Source: IKT, graphic: © Hanser

metry (DDSC) with a DSC 2 (manufacturer: Mettler Toledo, Greifensee, Switzerland). For the purpose, 4 mm-diameter circular chips were punched out of the films and automatically tested in aluminum crucibles. At the start of the measurement cycle, the test chamber was first cooled down to -80 °C and kept at this temperature for 5 min., then heated to 240 °C at 10 K/min., and cooled down to -80 °C again at -10 K/min. after two minutes isothermal phase, before the second heating process began. The second heating cycle was used to evaluate the changes in the thermal characteristics of the materials, for example the melt enthalpy and thus the necessary energy for melting.

The films were subsequently formed into cups in a comprehensive thermoforming study [8]. This was done using a laboratory thermoformer (type: LDFG32b; manufacturer: Illig Maschinenbau GmbH & Co. KG, Heilbronn, Germany). For performing the tests, a temperature-controlled negative cup mold was used. As can be seen from the flow chart of the thermoforming process (**Fig. 2**), the tensioning frame, together with the film, first moves between the radiant heaters, which heat the film to the forming temperature range. The subsequent forming was achieved with compressed air and vacuum, together with mechanical prestretching. The plug is driven by a servomotor, which prestretches the material into the mold cavity at a rate of 500 mm/s and a travel of 73 mm. The remainder of the forming is then reached shortly after the start of prestretching by the combination of compressed air and vacuum. After a holding phase, the thermoforming process is terminated by the opening of the mold. The basic parameters are shown in **Table 2**.

By varying the heating time, pressure and plug position, the aim was to find the optimum parameters for each film formulation, which were then used to manufacture at least five cups. For this, a cup was manufactured using a basic setting, and the result of the thermoforming was assessed. In the first quality analysis, poor forming definition, blow holes, poor surface quality, or uneven wall-thickness distribution led to rejection and changing of the setting parameters. With the collected empirical values, the best process settings for each material could then be found iteratively, by adjusting first the heating time and then the plug travel. The wall thickness distribution of the thermoformed cups was determined with a thickness gauge (Panametrics Magna Mike 8500; manufacturer: Olympus, Mainz, Germany).

To assess the part quality, the compression resistance according to DIN 55440–1 was determined on the manufactured cups with a universal tensile, compression and flexural testing machine (type: Zwick 1474; manufacturer: Zwick/Roell, Ulm, Germany). The test specimen, positioned between two pressure plates, is loaded axially by the raising of the lower pressure plate (advance rate 10 mm/min. ± 3 mm/min., initial load until measure-

Test	Basic material	Additive A	Additive B
1	100 % PP	–	–
2	90 % PP	10 % M1	–
3	90 % PP	10 % M2	–
4	90 % PP	5 % M1	5 % M2
5	87,5 % PP	10 % M1	2.5 % M3
6	90 % PP	5 % M1	5 % M3
7	95 % PP	5 % M3	–
8	92 % PP	5 % M3	3 % M4
9	92 % PP	5 % M1	3 % M4
10	87 % PP	10 % M1	3 % M4
11	97 % PP	3 % M4	–

Table 1. Overview of the different film formulations of the screening Source: IKT

Start time		Holding time			Temperature	
Plug	Pressure	Vacuum	Pressure	Vacuum	Mold	Heated tools 1-8
0.5 s	1 s	1s	10 s	10 s	70 °C	450 °C

Table 2. Non-varied process parameters Source: IKT

ment start 1 N). The forces occurring and the travel distance are recorded by a force-path sensor, until the test is terminated by a maximum compression path of 50 mm or a sudden drop of >20 % in resistance force. Five cups made from each film formulation were tested under standard climatic conditions.

Analysis of the Efficiency Potentials by Modification

The project uses an integrated analysis to demonstrate how the masterbatches influence the materials' resource efficiency. This article presents the efficiency potentials with one example in each case: the energy saving reached during processing as well as the material saving potential due to improvement of the product properties of a cup.

The measurement of the melt enthalpies of the reference material and modified formulations (**Fig. 3**) shows that the modifications in most cases mean that a reduction of the melt enthalpy can be expected. The reduction of the melt enthalpy here is a measure of the thermal and mechanical energy to be supplied during the extrusion process and was at most 15.8 %. In addition, the extrusion required lower die pressures and thus a reduction of about 10 to 20 % in the mechanical energy input. From rheological studies, this can be traced back to improved flowability of the blends, which is also an advantage for the thermoforming process, since the films manufactured can already be processed at lower temperature, which further saves up to 20 % of the heating time and enlarges the processing temperature window.

The material saving potential is elucidated by investigating the compression resistance of the manufactured cups (**Fig. 4**). For this, the maximum compression force of the 1 mm-thick reference film (53.6 N) is compared with the 0.7 mm-thick thermoformed films of the new formulations, with which maximum forces of up to 66.5 N to could be attained. This corresponds to an increase of the compression force of 24 % with simultaneous reduction of the wall thickness of 30 %. The increased compression resistance of the cups can be attributed to the increase of the material stiffness; at the same time, the addition of the masterbatches optimizes the thermoformability of the PP, so that a more uniform wall thickness distribution results.

Summary and Outlook

The results of the thermoforming trials show that suitable modification of polypropylene allows a material saving of over 30 %. This is achieved through improved thermoformability of the blend, manifested as a more uniform wall thickness distribution. Likewise, through the addition of the masterbatches from the project partner Constab, a reduction of the melt enthalpy was achieved, allowing an energy saving of up to 15 % in the film extrusion process. The developed materials are clearly superior to conventional polypropylene as regards conservation of resources.

Within the remaining project time, it is now to be tested how selected formulations can be processed when scaled up to an industrial thermoforming process on a production scale. Furthermore, it will be examined to what extent the positive results can be transferred to biobased plastics such as polylactides (PLA). ■