Closed-loop recycling of packaging waste at the food manufacturer Freiberger

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ABSTRACT: This work describes different approaches which lead to more environmentally friendly plastic waste management. Plastic waste was analysed using light microscopy, Raman spectroscopy, and differential scanning analysis. Afterward, the waste was sorted by polymer content and mechanically recycled. Recycled material was used to produce films for tertiary packaging (shrinkage films). One possibility is recycling only single-layer films from polyethylene (PE), another possibility is to recycle multilayer films consisting of PE, polyamide 6 (PA6), and ethylene vinyl alcohol copolymer (EVOH). Due to mixing films, and thus polymers, in a certain ratio, both approaches lead to recycled films with sufficient mechanical properties even without using any compatibilizers.
Two different kinds of films - (i) lightweight films from PE and (ii) biopolymers films – were tested as a replacement for stretch wraps (quaternary packaging). Due to their design, lightweight films don't fulfill the requirements for the packaging in the company. Out of seven different biopolymer films, three reached the required strength and toughness for the stretch wrap used in the company.
Recycled films can replace films used as tertiary packaging and reduce significantly the amount of plastic waste. Also using biopolymers films instead of conventional films can cut down the amount of non-degradable plastic waste.

1 INTRODUCTION

Packaging makes up an important part of food production both on side of suppliers and the manufacturer. Different kinds of packaging assure safe transport of goods as well as high quality of food products such as taste, smell, and colour. Therefore, plastic packaging provides a broad variety of properties, and their use in multilayer films enables tailoring properties, for example, films with desired medium barrier properties within excellent mechanical strength. However, the service life of plastic packaging is very short and at the end of it arises the problem of how to reuse or recycle such material to reduce plastic waste (Alipour et al. 2015), (Cenci-Goga et al. 2020).
Packing materials from ingredients become waste at the moment when ingredients are used in the manufacturing process. At the same time, new products need to be packed before transportation. A four-step packaging system is used for products in this study. Primary packaging is in direct contact with food, secondary packaging consists of cardboard boxes for food products, tertiary packaging is used for packing more boxes together, and quaternary packaging for wrapping goods on pallets to secure them during transportation. All of those packaging materials have a short service life and become waste before any degradation of their properties can occur. Using packing material that comes with the supplies as material for packaging manufactured products seems like a suitable way to reduce plastic waste.
The PizzaPack project aims to reduce the amount of plastic waste in PrimAs Tiefkühlprodukte GmbH. The main goal was to find a way to replace tertiary and quaternary packaging films with films containing a high amount of post-consumer recyclates (PCR). In order to fulfill this goal, the recycling process must be developed, or the existing system of packaging should be analysed and transformed into a closed-loop system.
The closed-loop system in waste management requires the cooperation of involved parties. Recycled packaging films should be returned to the PrimAs company to be reused or recycled again.

Such a system helps to considerably reduce the amount of waste because the material can be used as long as it has eligible properties. Not only does it reduce the amount of waste but also the amount of virgin polymers in packaging.

2 EXPERIMENTAL PART

A combination of light microscopy, Raman spectroscopy, and differential scanning calorimetry (DSC) was used to analyse plastic waste films. At first, the macrostructure was analysed with light microscopy. Secondly, the chemical composition of films was determined with spectroscopy methods and DSC. After analysis, films were chosen for recycling according to their recycling potential and also according to the make-up of plastic waste in PrimAs company (Scheuerer & Jesdinszki 2012).

Lab-scale recycling was done in the measuring mixer (Typ 350 E, Brabender GmbH) at 240 °C and 80 rpm. Before kneading, the material was washed in warm water (60 °C) with detergent and dried in an oven at 60 °C for at least 24 hours. Films from kneaded material were prepared in a vacuum press Type P200PV (Dr. Collin GmbH) at a maximal temperature of 210 °C and 190 bar. The two most promising recyclates were used for the upscaled recycling process.

Upscaled recycling was done in a compounder ZSE 18HP-48D (Leistzritz Extrusionstechnik GmbH) with a screw speed of 350 rpm and maximal temperature of 150 °C and 270 °C for PE films and multilayer films with PA6, respectively. Films from compounded material were produced by film casting (Flachfolien-Laboranlage 400, Pastik Maschinenbau) at 265 °C and speed 16,8 $m \cdot min^{-1}$ in TCKT GmbH, Wels.

Mechanical properties like tensile strength and elongation at break were measured on a universal testing machine (Zwick Z001, Zwick GmbH). Shrinkage tests were conducted according to ASTM-D 2732-03 in a silicon oil bath. To evaluate the transparency of the bar code scanner, the films were put on the bar code and tested if the universal bar code scanner, if it is possible to scan the code.

To test if the selected biopolymers could be used as stretch wraps tests on a stretch wrap machine (Flyer VA; Pamminger Verpackungstechnik GmbH, Linz) have been performed. Within the tests, the strain and the thickness of the films as well as the force on the packed goods have been measured.

3 WASTE ANALYSIS

Annual production of approximately 88 t of plastic waste was recorded as the actual state of the waste situation in PrimAs. The PizzaPack project started with the current state analysis of the waste, especially plastic waste.

The plastic waste in PrimAs can be in principle divided into two fractions: (i) transparent white films, i.e. composed of single-layer film from polyethylene (PE), and (ii) blue films, i.e. multilayer films composed mainly from polyethylene (PE), polyamide (PA) and ethylene vinyl alcohol copolymer (EVOH) with a different weight ratio of materials. On one hand, single-layer films are easily recyclable in a mechanical way, on the other hand, multilayer films are mostly considered unrecyclable because they are made of different immiscible polymers. Therefore, part of this project is to find a way how to mechanically recycle multilayer films and return them to the packaging process.

4 REPLACEMENT OF TERTIARY PACKAGING FILMS

4.1 Single-layer films

Films from low-density polyethylene (LDPE) are used as thermal biaxial shrink films (tertiary packaging).
The first step was a literature study of commercially available shrink films with high content of PCR. A practical test of those films proved that there were no obstacles to using shrink films containing PCR in the manufacturing process.
The next step was the implementation of mechanical recycling of plastic waste to produce shrink films and return the plastic waste to the packaging chain. The easiest way is to recycle only single-layer films composed of polyethylene. The recycled shrink film was produced from the PE single-layer films by compounding and blown film extrusion in collaboration with a recycling company.
As a result of mentioned tests, a shrink film with 65 % PCR is used in PrimAs as a standard shrink film at the present. The recycled part of the shrink film is made strictly from single-layer transparent PE films. However, the transparent white films are only one-fifth of the plastic waste and to reduce plastic waste significantly, the blue part of waste - multilayer films - has to be recycled too.

4.2 Multilayer films

The main problem with the recycling of multilayer films is their composition of immiscible polymers. Mixing immiscible polymers leads to material with worse properties than the original material. Properties of recycled materials can be improved by one of two approaches. One way is to find the best ratio of different polymers, and the other way is using a compatibilizer. Adequate compatibilizer should provide "bonding" between two immiscible polymers and thus improve the mechanical properties of a blend. The second approach becomes more challenging with more than two materials in the blend.
The whole recycling process was simulated in a lab. The films were cut into small pieces and washed afterward to remove any food remains. Paper labels were also removed during cutting. The cleaning process is necessary to obtain the transparency of the recycled film. Shrink film has to be transparent for scanning bar codes of packed products, and each impurity of films deteriorates the optical properties of recycled films, which are already not ideal since the input films are already coloured.
After washing, the films were dried in an oven before kneading. Blends with different ratios of packaging films and also some blends with different compatibilizers were prepared. Two multilayer films made of PA, PE, and EVOH and two different transparent PE films were used as input for the recycling process. Three compatibilizers were chosen, namely (i) conventional poly(ethylene-co-acrylic acid) and poly(ethylene-co-maleic acid) and (ii) unconventional 1,3-phenylene-bis-oxazoline and (iii) 1,4-phenylene-bis-oxazoline (La Mantia et al. 2001), (Scaffaro et al. 2003).
After kneading, films were prepared in the vacuum press. The thickness of the films was between 300 and 500 µm. Mechanical properties of these films, such as tensile strength and elongation at break, were tested. Two blends, with the best properties and composition close to the make-up of plastic waste in the company, were prepared for upscaling to semi-industry scale. For upscaled recycling, a compounder was used. Blends for compounding were prepared from four films. From each film was prepared granule in compounder and these granules were mixed in the desired ratio for final compounding. Pre-preparation of granules enabled getting a more homogenous blend than with unprocessed films. This kind of recycling produces approximately 25 µm thick films, which are closer to the commercial shrink film than pressed films. The mechanical properties of thin films were tested again and compared with the standard shrink film.

4.2.1 Shrinkage test

A shrinkage test was carried out with thin films as well as with standard shrink film. Shrinkage test in oil bath caused the maximal shrinkage both in machine directions and perpendicular to the machine direction. To simulate the shrinkage process in the company, the shrinkage of thin films was tested in an oven at elevated temperatures. During the test in the oven, the time-shrinkage dependency was measured. A simulation, where the film was shrunk around a box at raised temperature, was supposed to prove its usability. Also, transparency for bar code reading was tested after the shrinkage test.

Test on a small scale showed that it is possible to recycle multilayer film into shrink film with requested mechanical and optical properties. The next step is finding an industry partner to upscale recycling on an industry level. After that, recycling can be contemplated as feasible on an industrial scale.

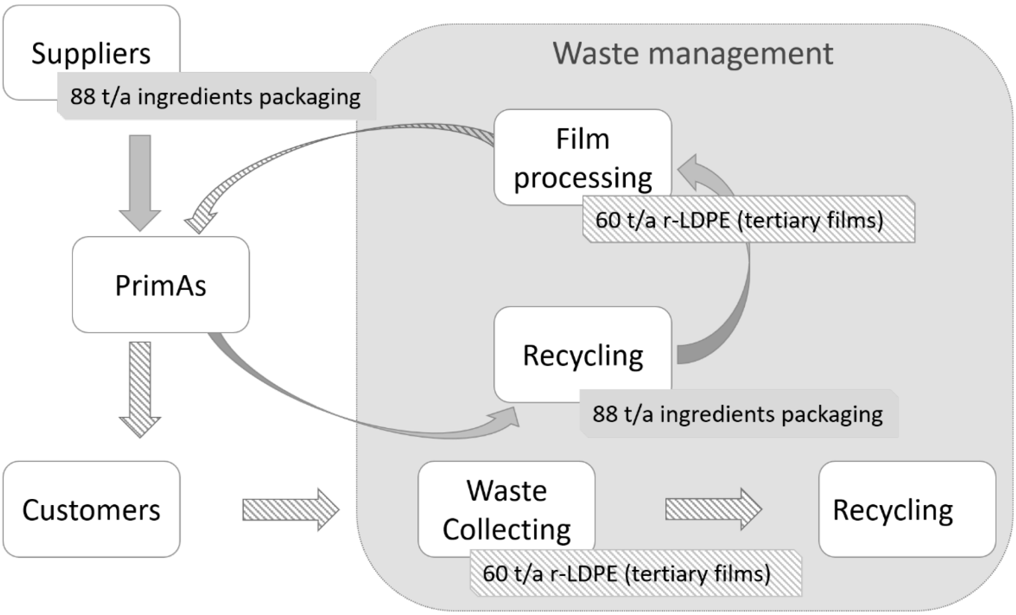

Fig. 1: Diagram of planned waste circulation in PrimAs company

5 REPLACEMENT OF QUATERNARY PACKAGING FILMS

Films from linear low-density polyethylene (LLDPE) are used as stretch films (quaternary packaging). These films are used for wrapping the goods on pallets for transportation. In this project, three possibilities for the replacement of LLDPE films were studied: (i) lightweight stretch films, (ii) biopolymer films, and (iii) stretch films containing PCR.

5.1 Ligthweigth stretch films

The lightweight stretch film is a commercially available variant of a stretch film. Its design allows using less raw material to produce the same amount of film. Lightweight stretch films contain regularly distributed perforations to reduce their mass. Such alternative stretch film was tested directly in the PrimAs company. The holes in the material allowed water to penetrate the goods, which could lead to damage to secondary packaging (cardboard). Also, the final reduction of material was smaller than expected.

5.2 Bio-films

Biopolymers are a more sustainable variant of conventional fossil-based plastics. Biodegradable polymers especially can help greatly with packaging sustainability. After the end of service life, biopolymers do not need to be incinerated but instead can be placed into the compost, where they degrade to harmless components (Yadav et al. 2018).
Seven different biopolymers were tested in the small-scale wrapping tests simulating wrapping pallets with stretch films. Chosen polymers were polybutylene adipate terephthalate (PBAT), starch and polylactic acid copolymer (starch-PLA), polyamide, starch polymer, and polylactic acid (PLA), and polybutylene succinate (PBS).
Films from PBAT, starch-PLA, and PLA had good strength and toughness and also good performance during the wrapping test. The next step is to upscale the test to the industry level, to prove the feasibility of bio-wrapping films.

5.3 Stretch films with PCR content

As with the tertiary packaging, there is also a possibility to use commercially available stretch films with PCR content. This alternative will be tested in the PrimAs and compared with formers.

6 FUTURE RESEARCH

The goal to create closed-loop packaging also incorporates the primary packaging films. These films are in direct contact with food. Therefore, there are high demands on them to keep quality and safety standards. Implementing recycling material, such as primary packaging, is a great challenge, and should be a focus of future research.
During the recycling arose a problem with labels on packaging film. For a manufacturer, labels are essential for recognizing materials and ingredients within, but create problems with recycling, since labels are commonly made out of paper that causes contamination of recycled material if not removed. To prevent impurities from paper labels in recycled films, the possibilities of reducing their size and switching to plastic labels are discussed.

7 CONCLUSION

In this study, the possibilities of reducing plastic waste by replacing virgin material with high PCR content material and by in-house waste recycling were presented. The following conclusions were drawn:

- Analysis of plastic waste is necessary for subsequent recycling. Information about each layer of films has to be obtained. This can be achieved by a combination of DSC and Raman spectroscopy.
- Replacement of tertiary packaging with commercially available films with high PCR content is possible without decreasing the quality of packaging, and it may be easily implemented.
- According to small-scale tests, it is feasible to produce shrink film from recycled single-layer as well as multilayer films with desired mechanical and optical properties.
- Lightweight stretch films didn't prove themselves as a sufficient replacement for the standard stretch films. Stretch films from biopolymers (PLA, PBAT, and a mixture of PLA with starch) showed good packaging properties in small-scale tests. Upscaling is needed to confirm its sufficiency as wrapping films.

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