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Cellulose Acetate Foams

Foam sheet extrusion of thermoplastics (e.g. extruded polystyrene foam (XPS)) is a well-established foam technology. Two basic categories of blowing agents are used for foam production (table 1). The blowing agent is the primary factor controlling the foam density as well as its cellular microstructure and morphology, so determining the end-use properties of foams [1].

Physical blowing agents (PBA)
▪ gases (e.g. N_2, CO_2, C_3H_8 or C_4H_{10}) or low boiling point-fluids (e.g. ethanol or propanol)
▪ separate feeding via gas injection into the polymer melt (homogenization zone)
▪ lower foam densities and higher foam ratios with more homogeneous foam morphology than for CBA
▪ thin-walled foam sheets, films or profiles

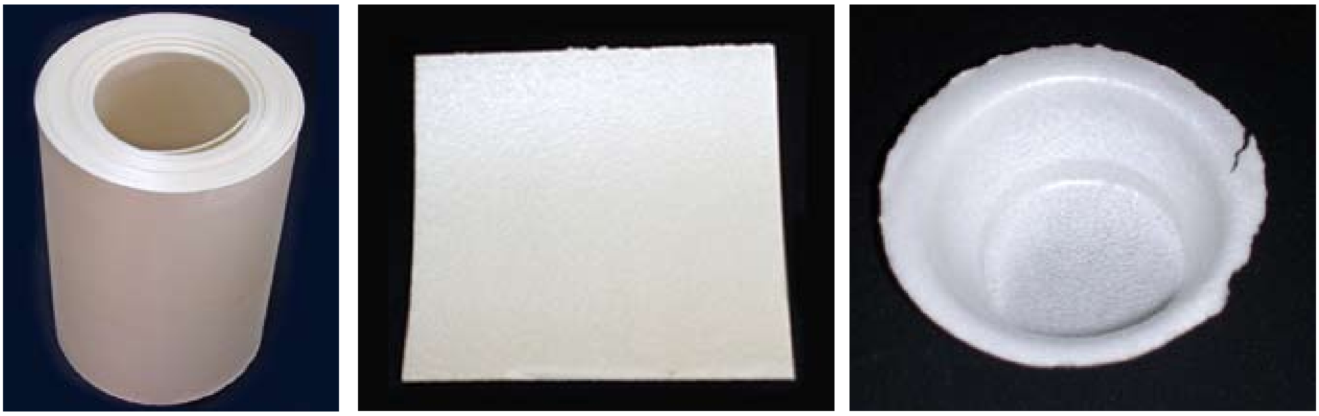
Chemical blowing agents (CBA)
▪ thermally unstable chemicals (e.g. bicarbonates, azodicarbonamide, hydrazine derivatives or citric acids) which decompose or react under temperature and produce gases (e.g. N_2, CO, CO_2)
▪ feeding as masterbatches together with the polymer (no critical modification of existing machinery is required in comparison to PBA)
▪ only thick-walled products with low density reduction

Table 1: Short characterization of physical and chemical blowing agents (according to [1] and [2]).

A wide range of conventional polymers is available for foam extrusion processes (e.g. PE, PP, PS, PET, PVC) [1;2]. Foams based on biopolymers (starch or PLA) are the subject of recent developments and are already available on the market, especially as food trays or particle foams [3]. At present the use PLA for the production and application of foam trays for hot contents is limited due to its low heat resistance. Furthermore, the thermoforming process of PLA-based foam sheets is critical with regard to the high crystallinity and brittleness of unmodified PLA. Therefore Fraunhofer UMSICHT, FKuR GmbH and Inde Plastik GmbH, a leading manufacturer of XPS-based food trays, are developing thermoformable Cellulose Acetate foam sheets for hot food applications. Foam tests with BIOGRADE C 7500CL and different chemical blowing agents (CBAs) produced foam sheets with good thermoforming behaviour (Fig. 1).

By adding an azodicarbonamide as a CBA to the extrusion process it was possible to reduce the density of BIOGRADE C 7500CL from 1.244 to 0.454 g/cm³. The Cellulose Acetate foams exhibit a coarse morphology with non-homogeneous distribution of the cells (Fig. 2). Furthermore, these bubbles are surrounded by compact Biograde C 7500CL as a matrix. The relatively low reduction in density and the coarse foam morphology with only a few, but large, cells is typical for foams produced with CBAs.

Fig. 1: Cellulose Acetate based foam sheets (right and centre) and thermoformed cup (left).



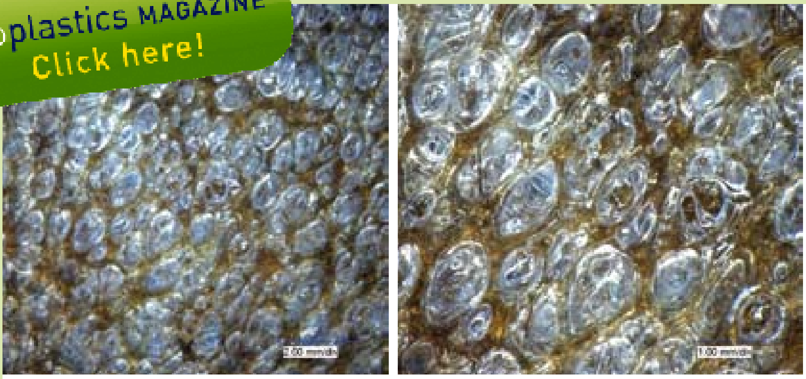


Fig. 2: Morphology of Cellulose Acetate foam (digital microscope; magnification: 25-times (left) and 50-times (right)).

Literature
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In comparison to an XPS produced with PBAs, the Cellulose Acetate foams are stiff and have a high tensile modulus due to the relatively high amount of compact matrix material around the bubbles determining the mechanical properties (Fig. 3).

The rigidity in combination with high heat resistance (Vicat A of Biograde C 7500CL is 111°C [4]) and thermoformability of these Cellulose Acetate foams make them attractive for rigid foam applications (e.g. trays for hot contents). Furthermore, the excellent injection mouldability together with the foaming performance of Biograde C 7500CL are ideal for the manufacturing of foam injection moulded compact parts with a (rigid) foam core. Recent developments by Fraunhofer UMSICHT and Inde Plastik GmbH are focusing on Cellulose Acetate foams produced with PBAs. The aims of the investigation are foams with lower densities, homogeneous cells and finer foam morphologies like XPS foams. For fine, low-density foams produced with PBAs, the polymer properties have to fulfil specific requirements [1]:

Rheological properties:

- specific melt viscosity and melt stability for a good gas dispersion and distribution as well as stable foam morphology without collapse

Thermal properties:

- wide processing window without thermal degradation to achieve a specific melt rheology
- crystallization behaviour of the polymer competing with the nucleation and growth of the bubbles
- heat distortion temperature and heat conductivity for a rapid increase in polymer viscosity to avoid foam collapse

Physical properties:

- high gas solubility in the polymer melt but poor gas solubility in the finished foam
- boiling point, molecular weight or vapour pressure of the physical blowing agent
- physical polymer properties such as molecular chain structure or degree of crystallinity

To achieve these required properties, Cellulose Acetate has to be modified. At present external (physical) plasticization is the most common method of Cellulose Acetate modification. Blending is very difficult due to its Hansen solubility parameter as well as the strong hydrogen bonds (Fig. 4) influencing the miscibility of Cellulose Acetate [5].

Therefore, Fraunhofer UMSICHT is studying the reactive modification (e.g. internal (chemical) plasticization) of Cellulose Acetate to achieve the long-term stable properties needed for physical foaming.

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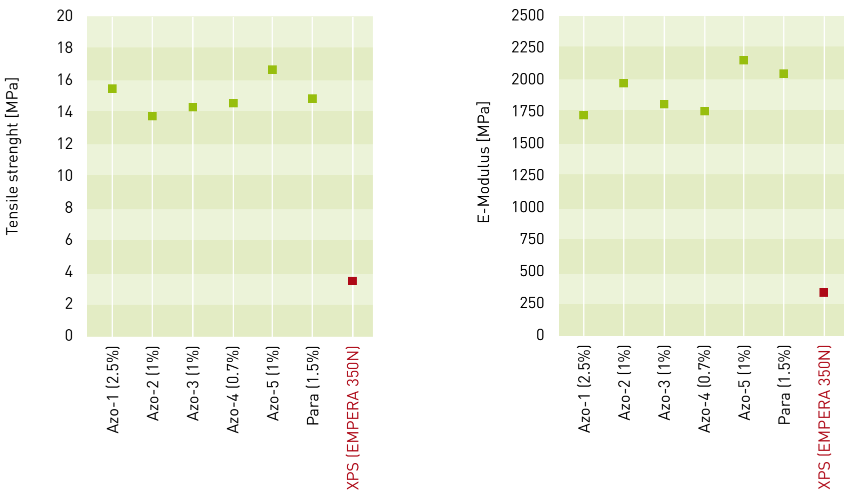
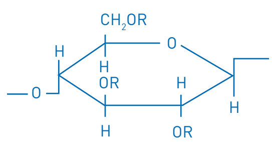


Fig. 3: E-modulus and tensile strength of different Cellulose Acetate foams in comparison to an XPS (red).



(R is $COCH_3$ or H)

Fig. 4: Molecular structure of Cellulose Acetate [6].