Turning Trees into Foam

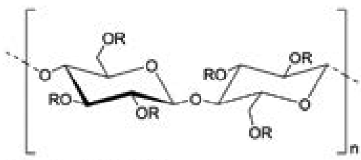
Particle Foams Made from Cellulose Esters for Large-Scale Production

Particle foams based on renewable cellulose derivatives could be an alternative to oil-based expanded polystyrene. In the context of a development project, researchers demonstrated that cellulose-based particle foams can be produced with varying densities using conventional processing equipment. In addition, these materials do not require halogen-containing flame retardants.

Potential products made from CAB and CP particle foams. The matrix materials are based on the renewable raw material cellulose, and on eco-friendly additives (© Fraunhofer ICT)

Sustainable construction materials and halogen-free flame retardants are attracting increasing public attention. Poresta systems GmbH, Bad Wildungen, Germany, and the Fraunhofer Institute for Chemical Technology ICT, Pfinztal, Germany, worked together in a publicly funded project to develop a particle foam based on renewable raw materials. This foam will provide an alternative to oil-based expanded polystyrene (EPS), and will meet the requirements for B2 construction materials according to DIN 4102 without the use of halogen-containing flame retardants. The aim was to develop foam particles from cellulose-based biopolymers, which, like EPS, can be sintered to form a structurally stable component using water vapor. The institute made its comprehensive pilot plant equipment available for extrusion and particle foam production in this project. The industrial partner contributed its long-standing experience in the industrial processing of particle foams and the conceptual design of the related component molds.

In order to investigate the processing chain for the manufacture of expandable, biobased pellets and their further processing into components, the raw polymers cellulose acetobutyrate (CAB) and cellulose propionate (CP) were chosen:



CP: R = $-CO-CH_2-CH_3$
CAB: R = $-CO-CH_3$ and $-CO-CH_2-CH_2-CH_3$

These are amorphous thermoplastics that are obtained by esterifying cellulose. They generally have a high impact strength and transparency. They are furthermore resistant to stress cracking and weather conditions, have a high tracking index, good electrical insulation properties, high hydrolysis and mineral oil resistance and extensive colorability [1]. Using injection molding processes, these polymers are usually processed into everyday objects such as frames for glasses or door handles.

Fire Behavior of Thermoplastic Foams

The factors that can influence the fire behavior of a foam are shown in **Figure 1**. A wide range of flame retardants can be used to attain flame-resistant properties in bulk polymers. Especially in the last few years, various halogen-free materials such as metal hydroxides and phosphor- or nitrogen-based flame retardants were added to the list. However, the required quantities of halogen-free flame retardants are detrimental to the expansion process of polymer foams, leading to negative impacts on density, foam structure and mechanical properties. This was confirmed by comprehensive investigations of polymer foams made from CAB and CP. As a result the particle foam production and resulting foam structures were optimized to improve fire behavior.

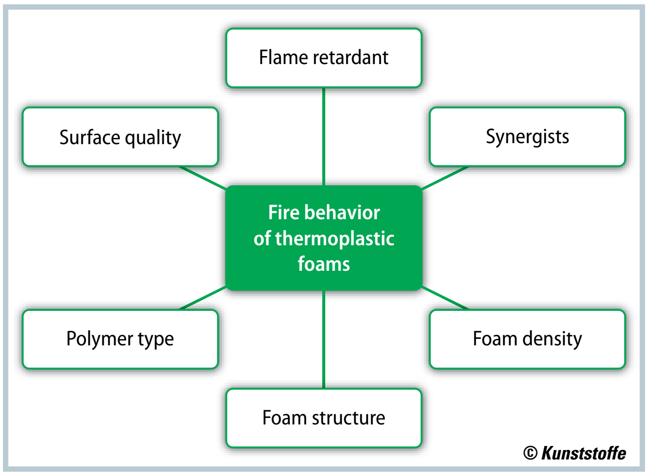


Fig. 1. Possible influencing factors on the fire behavior of a thermoplastic foam (source: Fraunhofer ICT)

Production of Foamable Pellets Containing Blowing Agents

To produce biopolymer pellets containing a blowing agent, the polymer is melted, mixed with a blowing agent and homogenized in an extruder (model: Leistritz Micro 27-40D, manufacturer: Leistritz Extrusionstechnik GmbH, Nürnberg, Germany). The polymer-gas mixture is then pelletized underwater in a closed circuit (UWG, model: Gala LPU, manufacturer: Gala Kunststoff- und Kautschukmaschinen GmbH, Xanten, Germany). During this process, the pellets cool down and are then transferred to a centrifugal dryer to remove the remaining process water (**Fig. 2**).

The challenge is to prevent the thermal degradation of the polymer in the perforated plate. Due to their chemical structure, cellulose-based polymers have a different thermal behavior to standard polymers such as polystyrene or polypropylene. Where standard microgranule perforated plates are used, this leads to the deposition of the material and its subsequent thermal degradation. The perforated plate was redesigned to prevent this. The amount and radii of the perforations was varied, allowing improved flow through the plate with a consistent throughput. In addition, it generated an optimal pressure drop and prevented material degradation.

Fig. 2. View of the extrusion line: During pellet production it was important to optimize the quality by regulating water pressure, temperature and blowing agent content (© Fraunhofer ICT)

The pellets containing blowing agent were pre-foamed on industrial units and then sintered to form molded parts. To achieve the lowest possible density range, tests were conducted with several different blowing agent contents and water pressures (UWG). These processing parameters are crucial, determining the foaming degree and the resulting density of a thermoplastic foam. **Figure 3** shows the bulk density of pre-foamed CP pellets as a function of the blowing agent content and water pressure.

The results of this test show that low densities for CP can be obtained using high blowing agent concentrations. After the quality of the pre-foamed pellets had been evaluated in the industrial process, the processing conditions of 6 bar water pressure and 8 % blowing agents were chosen. The best results for the processing of CAB were obtained with a reduced blowing agent content of 6 %.

Besides process control and parameter settings, other investigations were carried out on the material formulation, concerning the nucleating agents and other processing additives used. These could be adjusted to achieve components fulfilling DIN 4102 requirements for B2 construction materials with a density of ≥ 40 kg/m^3.

Industrial-Scale Production of Components

Figure 4 is a schematic diagram of the processing of pellets containing blowing agents into components. Using this »

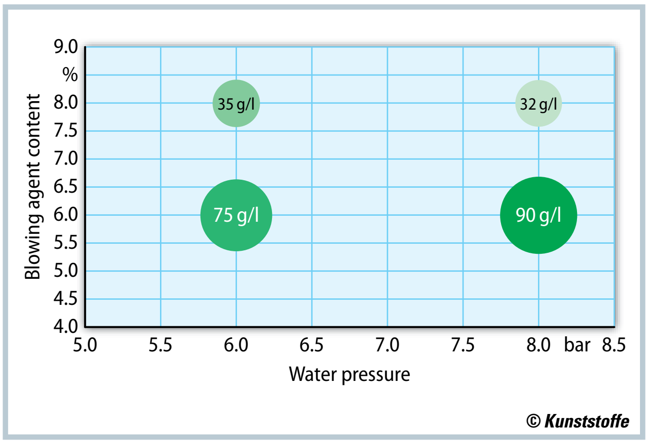


Fig. 3. Bulk density of CP as a function of blowing agent content and water pressure (source: Fraunhofer ICT)

The Authors

Dipl.-Ing. (FH) Anja Schneider works in the foam technologies group at the Fraunhofer Institute for Chemical Technology ICT in Pfinztal, Germany; anja.schneider@ict.fraunhofer.de

Florian Rapp, M.Sc., is the team leader of the foam technologies group at Fraunhofer ICT.

Dr. rer. nat. Karl Iglhaut is the Head of Product Development at poresta systems GmbH, Bad Wildungen, Germany; karl.iglhaut@poresta.com

Andreas Michel, certified technician for plastics processing, works in product development at poresta systems GmbH.

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technology, CP and CAB pellets containing blowing agents were investigated in terms of their processability into particle foam blocks (size 1,000 x 500 x 400 mm) and sheets (size 1,400 x 1,200 x 10–110 mm). The pellets were pre-foamed in a discontinuous pre-foamer (model: Händle KVD 950 A, manufacturer: Händle GmbH Maschinen- und Anlagenbau), and provisionally stored. During the pre-foaming of the CP and CAB pellets, bulk densities of 33–115 kg/m^3 and 34–136 kg/m^3 respectively could be achieved.

The pre-foamed CP and CAB pellets containing blowing agent could be processed into particle foam sheets in several different thicknesses with foam densities of 50–90 kg/m^3 in reliable serial production (**Fig. 5**). The further mechanical processing of the particle foam components made from CP and CAB foams can be compared to that of expanded polystyrene (EPS). The only difference in comparison to EPS is the higher degradation during thermal processing methods. This is due to the fact that during thermal processing, CP and CAB foams have a higher cutting resistance, which lowers the cutting speed and increases the thermal energy input into the component. The particle foam components were characterized according to their technical properties. **Table 1** shows a selection of important indices.

Conclusion

With CAB and CP as basic polymers, biobased foamed products can be reliably produced and processed on industrial units. The mechanical processing of the components, for example cutting or milling, is similar to that of expanded polystyrene (EPS). By adjusting the cell

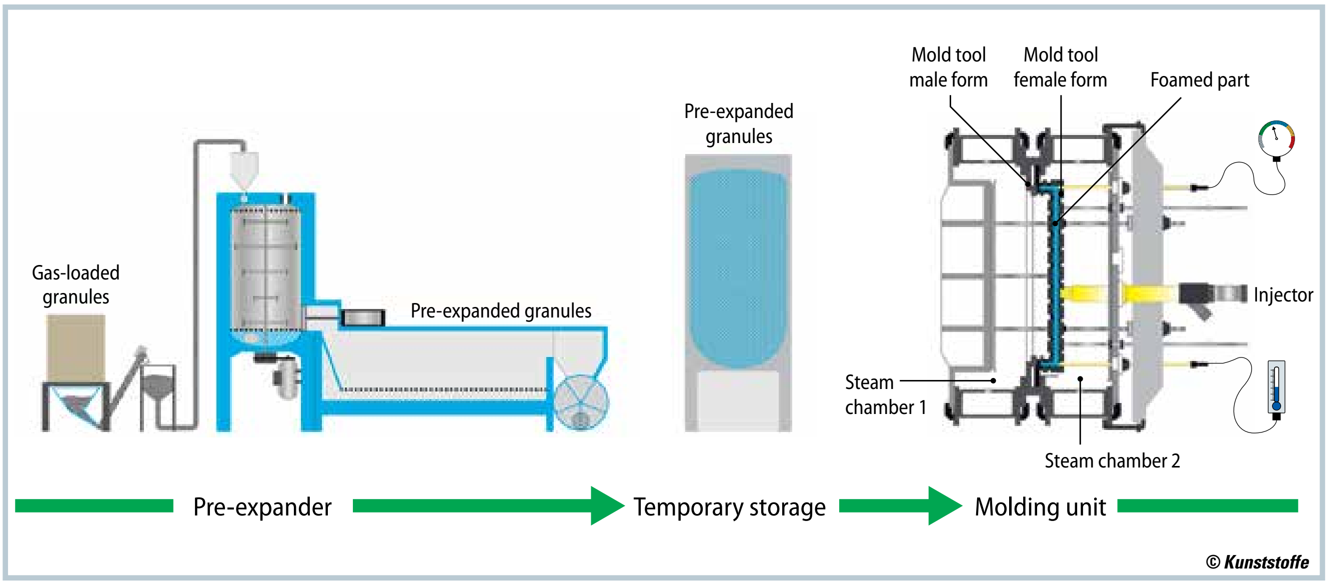

Fig. 4. Schematic diagram of the production process of a cellulose-based particle foam component (source: poresta systems/Kurtz)

Technical properties		Particle foam made from		
		CP with a density 81–89 kg/m³	CP with a density 48–52 kg/m³	CAB with a density 39–40 kg/m³
Compressive strength at 10 % compression DIN EN 826	[kPa]	359	164	186
Modulus of elasticity in compression DIN EN 826	[MPa]	12	5	8
Tensile strength DIN EN ISO 527	[kPa]	450	180	210
Bending strength of 20 mm plate DIN EN 12089	[kPa]	710	226	265
Fire behavior DIN 4102 freely suspended	-	B2 plate thickness ≥ 60 mm	B2 plate thickness ≥ 40 mm	B2 plate thickness ≥ 60 mm
Heat deflection according to DIN EN 1605	[%]	< 4	< 4	-
Thermal conductivity DIN EN 12667	[W/(mK)]	0.040	0.036	0.037

Table 1. Overview of the technical and mechanical properties of CP and CAB particle foams (source: poresta systems GmbH)

Fig. 5. Cross-section through a particle foam made from cellulose propionate, with a density of 92 kg/m³ (© poresta systems)

structure and density of CAB and CP particle foams and using suitable processing additives, materials can be produced which meet the requirements for B2 construction materials (DIN 4102) in a density range of 40–90 kg/m³, even without the use of flame retardants. Matrices based on renewable raw materials and eco-friendly additives make particle foams more sustainable and resource efficient.

The large-scale sintering of pre-foamed pellets containing blowing agents to form cellulose-based components has already been achieved. However, the production capacity for expandable pellets containing blowing agents is currently still dependent on the capacity of the pilot plant. For greater production outputs, large-scale production possibilities are needed.

Besides the general properties of foams, such as material savings due to lower densities and a high lightweight potential, the biopolymer foam also has a significantly higher heat resistance than EPS. It is therefore suitable for other areas of application, for example as a thermal insulation material for higher temperature ranges or the housing of units. ■