Porous lyocell powders as sound absorbers

Marco Beaumont · Blasius Buchegger · Sven F. Plappert · Jean-Marie Nedelec ·
Martina Opietnik · Antje Potthast · Thomas Rosenau

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Abstract Environmentally friendly insulation materials based on renewable resources come more and more to the fore, replacing less sustainable materials, such as mineral wool or polystyrene foams. In this study, we present a straight-forward avenue to a highly porous cellulose II powder for application as sound absorber. The material was prepared from a lyocell-derived cellulose II gel by a freeze-drying approach. The powder has a porosity of 98% and a specific surface area of 177 m²/g. It featured a sound

absorption maximum in the frequency range of one-third-octave bands of 400–800 Hz (65 mm thickness) and was significantly more efficient as acoustic insulation material than commercial alternatives. The high performance makes the cellulose II sound absorber especially attractive for a use in loudspeakers for small electronics.

Marco Beaumont and Blasius Buchegger have contributed equally to this study.

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M. Beaumont (✉) · S. F. Plappert · A. Potthast
Division of Chemistry of Renewable Resources,
Department of Chemistry, University of Natural
Resources and Life Sciences, Vienna (BOKU), Konrad-
Lorenz-Straße 24, 3430 Tulln, Austria
e-mail: marcobeumont1@gmail.com

T. Rosenau (✉)
Division of Chemistry of Renewable Resources,
Department of Chemistry, University of Natural
Resources and Life Sciences, Vienna (BOKU),
1190 Vienna, Austria
e-mail: thomas.rosenau@boku.ac.at

B. Buchegger
Labor für Bauphysik, Graz University of Technology,
Inffeldgasse 24, 8010 Graz, Austria

S. F. Plappert · J.-M. Nedelec
CNRS, SIGMA Clermont, ICCF, Université Clermont
Auvergne, 63000 Clermont-Ferrand, France

M. Opietnik
Lenzing AG, Werkstraße 2, 4860 Lenzing, Austria

T. Rosenau
Johan Gadolin Process Chemistry Centre, Åbo Akademi
University, Porthansgatan 3, 20500 Åbo/Turku, Finland

Graphical Abstract

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Sound-absorbing materials take up most of the sound energy striking them and reflect only very little (Arenas and Crocker 2010). This property is measured by the sound absorption coefficient ($\alpha \leq 1$), which is the ratio between the absorbed and incident sound intensity. This value is especially high in the case of open-porous materials (Crocker and Arenas 2008). Conventional sound absorbers are mineral wool or polystyrene foams. Due to environmental concerns, environmentally friendly, sustainable and renewable insulation materials come more and more to the fore as “green” alternatives to these conventional absorbers (Arenas and Crocker 2010). Plant-based cellulose materials are promising candidates in this respect. In the literature, most acoustical behavior studies have been conducted on materials consisting of cellulose microfibrils (Zulkifli et al. 2008; Putra et al. 2013; Yeon et al. 2014; Pöhler et al. 2016; Nechita and Năstac 2018). In this study, we aimed at increasing the efficiency of cellulosic sound absorbers by using a previously described cellulose II gel *i.e.* lyocell gel (Männer et al. 2015; Beaumont et al. 2016). This gel can be classified as nanocellulose and is a precursor to highly porous, aerogel-like materials (Beaumont et al. 2017). It is produced by an industrial cellulose fiber production process (lyocell process) in a captivatingly energy-efficient way, which is much more sustainable than

conventional cellulose I nanofibril manufacture (Beaumont et al. 2016).

The cellulose II gel (provided by Lenzing AG, Austria) was converted to porous powders by freeze-drying from a mixture of *tert*-butanol and water, a facile and fast approach that is schematically shown in Fig. 1. The possibility to obtain highly porous materials from cellulose gels by freeze-drying is well described in the literature, but it usually involves time-consuming solvent-exchange steps (Jiang and Hsieh 2014; Beaumont et al. 2016, 2017). The approach presented in this paper is more straight-forward and more efficient. The cellulose II gel, a 4 wt% aqueous suspension, was diluted with *tert*-BuOH to a solid content of 0.5 wt% and freeze-dried with pre-freezing at -80°C .

Scanning electron microscopy (SEM) as illustrated in Fig. 1 showed that the freeze-dried samples consisted of individual particles featuring an open-porous and fibrillar structure. The dry powder had a bulk density of 28 mg/cm^3 and a porosity of 98.2%. The high porosity is also reflected in the high specific surface area of $177\text{ m}^2/\text{g}$, which is in the same range as for cellulose I nanofibril cryogels (Jiang and Hsieh 2014). The pore size distribution was determined by nitrogen sorption experiments (Figure S1) showing a preserved nanoporous structure (pores of 2–100 nm) with a cumulative pore volume of $0.75\text{ cm}^3/\text{g}$ and an average mesopore diameter of 13 nm. The volume mean particle size of the powder was $28\text{ }\mu\text{m}$, see Figure S2 for the particle size distribution. The particle-like morphology is exemplarily shown in the SEM micrograph in Figure S3.

The idea to use these materials in acoustic absorption resulted from their high porosity and the open-porous structure, both features being requirements for good acoustic absorbers. The acoustic properties of the powder were analyzed in an impedance tube (Fig. 2a). The results of the measurements are shown in Fig. 2b.

A commercial cellulose fiber insulant for blown-in insulation and mineral wool were used for comparison and all measurements were performed on test specimens of 65 mm thickness. The commercial acoustic absorbers featured a similar acoustic absorption characteristic with absorption maxima at frequencies higher than one-third octave bands of 800 Hz. In general, the absorption maxima of materials can be shifted to lower frequencies by increasing the thickness of the absorber and to higher frequencies by

Fig. 1 Schematic of the preparation process of cellulose II powders. The structure of the particles was analyzed by scanning electron microscopy (SEM), showing a fibrillar and

open-porous structure. The table in the lower part of the figure shows a summary of their properties. $D[4,3]$ is the volume mean diameter

Fig. 2 Impedance tube for measurement of acoustic properties (a). Comparison of the acoustic absorption of the cellulose II powder with commercial cellulose and mineral wool insulation materials (b). The orange arrow visualizes the drastic shift of the absorption maximum to lower frequencies in the case of the cellulose II powder

decreasing it (Chu et al. 2017). That means that the lower the absorption maxima of materials with a fixed thickness, the higher is their efficiency as sound absorbers. The absorption curve of the cellulose II powder in Fig. 2 shows its absorption maximum to be in the frequency range of one-third octave bands of 400–800 Hz, which covers a wide frequency range of the human voice (100–900 Hz) (Clifton et al. 2006). In comparison to the commercial insulants tested, usually

high-priced products, the absorption maximum of the cellulose II powder is significantly shifted to lower frequencies. The here-prepared cellulose II powders thus are considerably more efficient as sound absorber. Their high potential as acoustic absorber is currently tested with regard to applications in loudspeakers in small electronics or hifi systems. This is accompanied by further improvements of the acoustic performance

and by further simplification of the manufacturing process.

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