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Processing of plant based fibrous materials with a disc mill

By means of a novel technology wet preserved hemp and other fibrous raw materials can be manufactured to innovative composite boards. Detailed examinations regarding the preparation attributes of such materials in a disk mill were carried out in a pilot plant. Substantial influence factors like kind of material and its structure as well as process and design parameters of the machine were analysed. The results show that the quality of the final fibrous material is mainly determined by the source of raw material. Process parameters and the design of the grinding plates have only a limited influence on the result of grinding up.

Keywords
Hemp fibres, wet preservation, defibration extruder, disk mill

Abstract
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In past years, a novel procedure for supply and processing of hemp and other fibrous materials has been designed at the Leibniz Institute for Agricultural Engineering Potsdam-Bornim. The procedure is based on wet preservation of fibre crops and the following processing to fibre composites (boards). A pilot plant was set up and is in operation for proving and experiments. Fibre crops e.g. hemp are chopped at normal harvest time and afterwards stored in a silo under anaerobic conditions [1; 2]. According to requirements, the stored plant material is processed into fibrous material by means of a defibration extruder and a disc mill. After drying and application of binders the resulting intermediate can be pressed to fibre boards [3].

Investigations concerning the grinding processes in the disc mill and the influence of the process control on the resulting fibre morphology are the focus of actual research work. A prospective goal is the production and supply of fibrous material which is suitable for natural fibre reinforced composites (plastics).

Process

The considerably important machines of the pilot plant for particle disintegration are a defibration extruder B90e and a disc mill. The extruder is used for the first grinding resp. defibration step and is equipped with two horizontal counter rotating screw shafts. The defibration occurs because of the changing free volume in between the two screws channels and the resulting pressure. Furthermore, the effect of the defibration is attributed to shear forces. Due to friction between the fibrous particles among each other and the screw channel resp. the screw tube an intensive heat generation is to be considered which encourages the defibration effect [4].

Subsequently the fibrous material passes the disc mill under atmospheric pressure in order to increase the degree of defibration. The effect of plasticizing under heat energy in the extruder has a positive effect at this stage [4]. The grinding of the fibrous material occurs between the fixed (stator) and the rotating (rotor) disc, which both are equipped with adapted kinds of fluting. If a certain level of shear resp. compression forces is exceeded, fibre elements (bundles or collectives of them) are disrupted resulting in an appreciable shortening [5]. Furthermore, friction forces appear due to interaction of fibre elements among each other or with the surface of the disc fluting.

Material and Methods

Experimental investigations were carried out in a disc mill in order to evaluate the defibration conditions of fibre plant material. The influence of different parameters on the resulting fibre quality was analysed:

- Raw material (hemp, soft wood, hemp shives, reed)
- Date of harvesting of hemp and dry matter content
- Kind of disc fluting
- Rotation speed of the mill disc (1 000–3 000 min^{-1})
- Distance between the mill discs (0,1–1 mm)

The investigations were carried out especially with wet preserved hemp (variety Fedora 17) of 2009 harvest period. Additionally soft wood chips, hemp shives, reed as well as a mixture of 30 % soft wood chips and 70 % wet preserved hemp were used in order to compare the milling process and the resulting fibre morphology. A preliminary defibration took place in the extruder prior the processing in the disc mill.

The resulting grinding degree in regard of different process parameters was characterized by means of the particle size distribution. The image analysis program „FibreShape“ is suitable for this purpose. Specific parameters like aspect ratio as well as length weighted fibre length and width were determined based on the size distributions.

Results

Above all, the reinforcing potential of (natural) fibres in composites is depending on the fibre length and the aspect ratio. Higher aspect ratios enable increased strength and stiffness properties of such composite materials [6; 7].

The selected raw materials showed considerable differences of product quality after defibration in the disc mill (**figure 1**). A clearly higher aspect ratio of 39 for the wood based fibre material was found out in comparison to pure hemp with 11. This value could be more than doubled by addition of 30 % wood.

The investigations regarding the influence of process parameters like rotation speed or disc gap do not show clear results until now. Only slight differences were determined for the resulting particle size distributions of different kind of fluting as well.

The dry matter content of the wet preserved raw material in stock is dependent on the harvesting date. A considerable shorting of the material occurs if later harvested and consequently dryer material is processed in the disc mill (**figure 2**). The median of fibre length and width are reduced which is resulting in a decreasing aspect ratio by increasing dry matter content.

Within the described supply procedure, the whole plant including leaves and seeds is utilized and processed. Thus, the resulting fibrous material contains considerable amounts of dust like ultra short fibres. This fraction is dedicated to be an impurity without any reinforcing effect in a composite due to the small aspect ratio. A subsequent fractionation or dedusting of the intermediate seems to be necessary.

Exemplary the dust content in the particle size distribution of a selected fibrous material was determined. Particles with fibre length of < 90 µm were defined as dust. The determination of the particle size distribution without this fraction showed a different result (**figure 3**). Especially the values of fibre length and aspect ratio were above the previous level. A sieve drum separator (condensor) was used for an experimental dedusting. The resulting fibrous material had different properties regarding fibre length and aspect ratio, which was increased to a level of 14.

Conclusions

Significant differences of the fibrous material quality could be determined only in regard to the kind of processed raw materials. The influence of process and machine parameters (disc gap and rotation speed) as well as kind of fluting seems to be unimportant. Further detailed investigations are necessary and planed in regard of the defibration behaviour of the extruder as well. Furthermore plasticizing of the raw material by means of steam in order to soften the containing lignin is scheduled. Specific attention will be put on the material flow in the disc mill and the development of a model to describe such grinding processes.

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Fig. 1

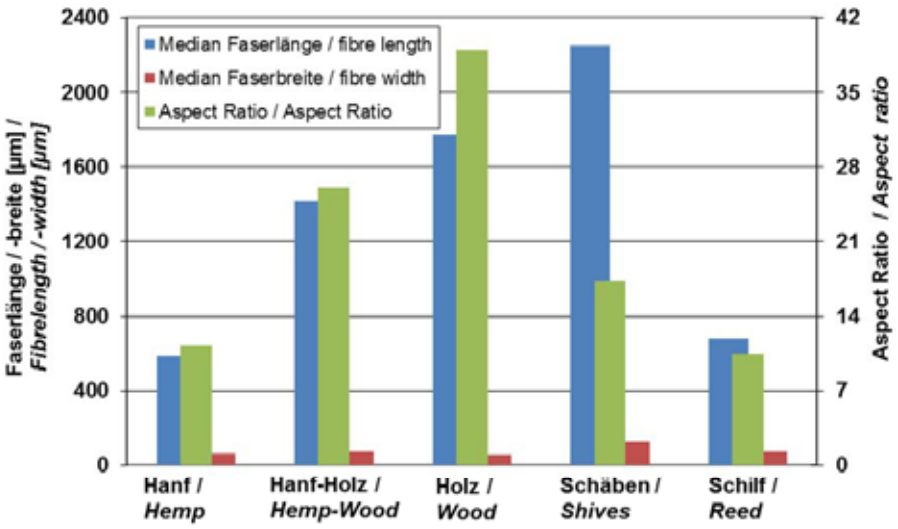

Fig. 1: Length weighted characteristics of the particle size distribution of different fibrous materials (extruded and milled – disc gap: 0.2 mm, rotation speed: 2 000 min^{-1})

Fig. 2

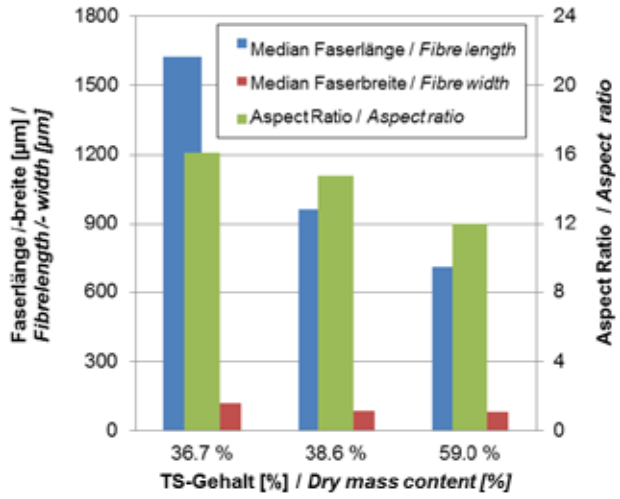

Fig. 2: Length weighted characteristics of the particle size distribution for fibrous material based on wet preserved hemp with different dry matter contents (extruded and milled – disc gap: 0.1 mm, rotation speed: 2000 min^{-1})

Fig. 3

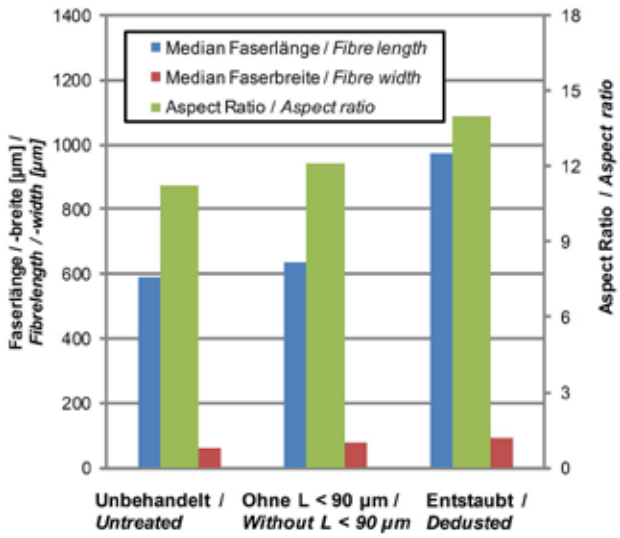

Fig. 3: Length weighted characteristics of the particle size distribution for fibrous material based on wet preserved hemp: untreated, fractionated (without L < 90 µm) and dedusted with a condenser

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