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FIBROUS RAW MATERIALS FROM AN ALTERNATIVE SUPPLY CHAIN FOR BUILDING PRODUCTS

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Abstract

In the traditional process fibre crops like hemp are mowed at harvest time, dried on the field and usually retted, too. An alternative supply chain proceeds chopping of the crop from the stand and its wet preservation thereafter. Bunker silos or foil wrapped silos are used for this storage procedure as known for example for animal fodder. The duration of wet preservation can be prolonged up to the next year's harvest without negative impact on mechanical properties of the single fibre element. By a new procedure the desired semi-finished or final product is processed from the preserved material directly, using the whole plant mass. This is carried out through an extruder mill and a refiner. A drying and further handling can follow in order to e.g. manufacture fibre boards. Further preliminary experiments were carried out for the utilization of wet preserved whole crop raw material as well as extruded respectively milled fibrous intermediates in mineral bonded building materials. Samples from the different stages of the supply and processing chain were analysed for their chemical composition, particle morphology and final product properties.

Keywords:

Alternative whole crop utilization, hemp, wet preservation, fibre boards, mineral bond composites

1 INTRODUCTION

Mainly separated components of fibre crops, in particular the constituents of the bast layer as well particles of the woody core, have been used as building materials already for decades [Klauditz et al. 1958; Deppe & Stashevski 1974; Atchison & Collins 1976; Allin 2005; Kymäläinen & Sjöberg 2008]. But as well common agricultural by-products and wastes have been subject of R&D activities respectively of practical applications. In particular the utilization of cereal straw for the production of particle boards has already a long tradition [Sheperd 1932; Oman 1955; Groner & Barbour 1971; Hesch 1978; Heller 1980].

Bast fibre crops like hemp and flax gained an increased interest based on changes of the EU production quota and subsidises policies in agriculture mid of 1980`s. Major markets for flax and hemp are the apparel sector for the former as well as pulp and paper and reinforced plastics for the latter. Many product developments have been introduced to the building market as well but the share on the overall market volume remains relatively small. Major constrains are the competiveness to established materials (e.g. to glass or mineral fibre insulation materials) as well as the available raw material volumes (e.g. fibre and particle board production). Nevertheless a continuously growing interest can be recognized from the public as the awareness on healthy living conditions and the utilization of sustainable, low emitting and energy saving raw materials in the building sector is rising.

The traditional supply chain for flax and hemp requires the use of specialized and costly harvesting and processing machines as well as is characterized by a high weather dependency of retting and field drying [Amaducci & Gusovius 2010].

Due to the competition situations regarding available growing area on one hand and to other raw materials in industrial applications the yearly production of industrial hemp was strongly fluctuating in past 25 years. Other factors have been the unpredictable and unbalanced changes of the political measures (e.g. agriculture, energy) of the EU since 1999. The recently arising interest in cannabinoids is leading to a steady growth of the acreage [Carus 2016] and is enabling new possibilities for product and market developments.

2 MATERIAL AND METHODS

2.1 Raw material supply and processing

An alternative supply and processing chain for hemp, other fibre crops or lignocellulosic feedstocks was developed at ATB in recent years. The traditional harvest and post-harvest procedures in particular for bast fibre crops are based on the drying and retting of whole or shortened stalks. Once the material is reaching the requested quality it is commonly compacted into bales and afterwards further processed. The main characteristics of widely practised bast fibre crops processing are the decortication (mechanically disintegration of the stalk structure), the separation of fibrous and non-fibrous parts as well as their refining. Unless a considerable technological progress related difficulties along this supply chain, partly high investments and better income possibilities with traditional crops strongly influence the development of bast fibre industry in Europe.

The new procedure is developed in order to simplify the process steps in the agricultural as well the post harvest part of the supply chain [Pecenka et al. 2007]. The initial subject and still the main focussed raw material is industrial hemp which is harvested and shred by means of a field chopper. Wet preservation under anaerobic conditions is carried out with the resulting whole crop material similar to the production of silage fodder (Fig. 1). The biomass can include leaves and flower/seed heads depending on the specific situation of value added.

Fig. 1: Harvest and storage of wet preserved hemp

Usually available machines and facilities at farm or contractors level can be used without or with only minor modifications. Important issues to be recognized are the realization of a proper chopping length and suitable moisture content of the crop at harvest time. Otherwise the necessary densification cannot be guaranteed and failed preservation processes lead to mould followed by deterioration of fibre properties [Idler et al. 2011]. Ensiling in traditional concrete bunker silos as well as foil tubes or wrapped bales is technically possible and successfully realized in past years.

Results of basic experiments have shown that a storage period up to the next harvest is possible without substantial influence on the raw material quality. The utilization of a preservation agent seems not to be necessary.

A pilot plant was established at ATB in order to carry out R&D on following processing and product manufacturing through a larger than lab scaled equipment (Fig. 2).

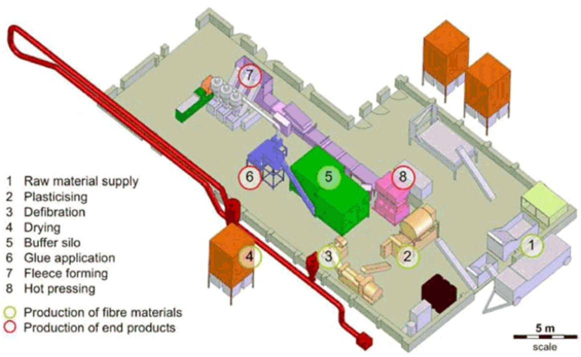

Fig. 2: Pilot plant for the processing of wet preserved hemp and other biomasses

Not only wet preserved hemp but also other biomasses like flax and linseed, bamboo or forest and short rotation based wood have been subject of respective experiments in recent years [Pecenka et al. 2009]. Furthermore, mixtures of different raw materials e.g. wet preserved hemp and wood chips have been used to achieve specific intermediate qualities for the manufacture of fibre boards as well.

The initial raw material processing consists of a two-step particle disintegration by means of a defibration extruder and a disc mill (Fig. 3). The throughput of these devices is projected to 300 kg.h^{-1} DM (about 1000 kg.h^{-1} at initial moisture content).

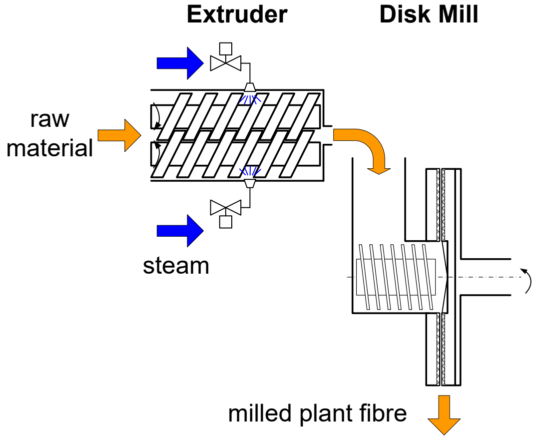

Fig. 3: Raw material processing with a defibration extruder and a disc mill

The working principle of the extruder is based on an insertion of shear and friction forces on the processed raw material by the design and effect of the two screws as well as the concurrent increase of pressure and temperature. A disc mill can be used in order to further influence and equalize the initial particle size distribution. Shear and compression as well as friction within the biomass fractions as well as between those particles and the specific designed mill discs leads commonly to a further size reduction of the fibres [Wallot et al. 2012]. The type and moisture content of raw materials, operating parameters of the two machines (e.g. rotating speed) and the selection of the respective disc profiles are key parameters for the achievement of a specific particle morphology.

Subsequently a drying of the mechanically processed fibrous material is necessary in order to enable further application or storage of the intermediate. A flash/ stream dryer is used to reduce the initial moisture content of about 65 % to at least 10 … 15 % (Fig. 2, position 4). The processing with the disc mill and the drying process are enabling as well the decompaction of the material which is commonly resulting from the extrusion process (Fig. 4).

Fig. 4: Wet extruded fibre material (left) and dried fibre material after milling and drying (right)

The intermediate fibre material has been used within the process line of the pilot plant for the manufacturing of fibre boards but also as reinforcement for mineral bonded building materials or composites [Gusovius et al. 2016].

In order to manufacture boards the intermediate fibrous material has to be glued and prefabricated into a fleece prior the final pressing. For the application of the binding agent a prototype of a mixing machine has been developed (Fig. 2, position 7; Fig. 5). Two rotating paddle shafts equally distribute the fibre material in the chamber space while the glue is spread on the individualized particles by four two-phase spay nozzles [Radosavljevic et al. 2009].

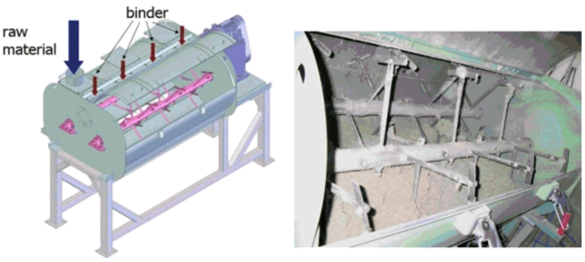

Fig. 5: Mixing machine for the application of binding agents to the fibrous intermediate

Several adhesives has been used and tested in order to assess their technical capabilities for the manufacturing of fibre boards based on wet preserved hemp and other biomass materials. This, both synthetic (e.g. phenolic and urea formaldehyde resins) and bio-based binding agents (e.g. canola press cake, agglutinated starch) have been under investigation [Pecenka et al. 2009, Krilovs et al. 2013].

A specific airlay fleece line is available at the pilot plant in order to equalize the material flow and to be able to form an up to 3 layer fibre fleece (Fig. 2, position 7).

Finally the prefabricate is compacted to commonly flat fibre boards by the use of a heating press with tool dimensions of 1200 x 800 cm and max. temperature of 220°C (Fig. 2, position 8). The press is equipped with a computer based control system enabling the realization of respective, cycled heat and press programs (Fig. 5).

Fig. 5: Heating press and selected product samples

Mineral bond composites have been manufactured only within preliminary experiments. Raw and processed hemp from wet preservation has been used at initial moisture content for manual mixture and block forming with concrete screed, mortar and lime (Fig. 6).

The test specimens had dimensions of L = 240 mm, W = 115 mm and H = 80 mm. They have been dried under ambient conditions directly after formation.

Fig. 6: Component mixing and forming of test blocks

2.2 Raw material product characterization

The material composition of hemp prior and in course of wet preservation is characterized by established methods for the analysis of “crude fibre” and gas or liquid chromatography [Idler et al. 2011].

The characterization of fibre morphology was carried out by means of the image analysis program FibreShape©. The generated particle size distributions are used for the calculation of detailed particle size analysis for geometric parameters like aspect ratio and the length-weighted 50th percentile of the fibre length/width.

A material testing machine Zwick-Roell Z010 ProLine and its respective test procedures have been used for the mechanical characterization of intermediates and products. These have been DIN EN 310 for the bending strength of fibre boards as well as DIN 105/DIN EN 771 for mineral bricks.

3 RESULTS

3.1 Raw material and fibre properties

Wet preservation of a biomass material like chopped hemp is based on the metabolism of anaerobic bacteria and resulting in a degradation of several building blocks of the plant, e.g. cell wall components. In the specific case sugars and short-chained carbohydrates are decomposed by respective enzymes. These processes are resulting in a low pH-value and the development of a number of organic acids and alcohols (Tab. 1).

Table 1: Characterization of wet preserved hemp and products thereof

	Dry matter [%]	Alcohols [% DM] *	Acids [% DM] **
Wet preserved hemp (sample 1)	25,9	0,49	7,75
Wet preserved hemp (sample 2)	26,2	0,43	8,27
Wood chips	85,9	n.d.	0,02
Product 1	93,9	n.d.	0,29
Product 2	93,3	n.d.	0,72

* Ethanol and propanol
** Acetic, lactic, propionic, n & i butyric, n & i valaric, and capronic acid
n.d.: not detected

A specific odour appears in the raw material but is reduced by temperature exposure in the course of following processing steps and product handling [Pecenka et al. 2009]. Further analyses have shown that the dry matter content is not significantly reduced in the course of preservation up to 12 month [Idler et al. 2011]. It can therefore be concluded that only the pectinolitic cell wall substances are degraded and the effect of wet preservation is to be characterized as similar to the traditional retting of fibre crops (Fig. 7).

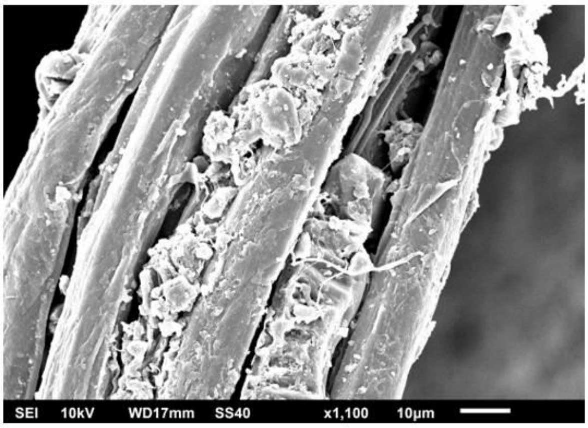

Fig. 7: SEM picture of wet preserved hemp fibre bundle

Investigations on mechanical and morphological fibre properties indicate a substantial influence of wet preservation [Wallot et al. 2012]. It was shown that in particular fibre bundles are refined in course of the storage process while their strength is decreasing.

The fibre geometry resulting from the primary processing of the wet preserved raw material is one of the most important factors for the quality of end products like fibre boards. The defibration with the extruder and the milling with the refiner have a substantial impact on the length as well as the width of the containing particle structure (which are mainly fibre bundles and collectives thereof as well as shives and fibres thereof) in the resulting intermediate (Fig. 8).

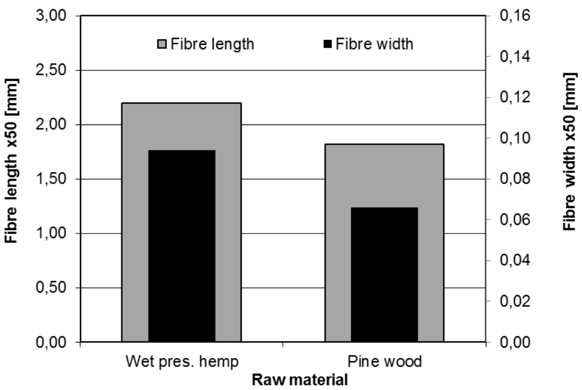

Fig. 8: Geometric fibre properties resulting from defibration at ATB pilot plant

The results show a similar geometrical relation of bast to wood fibres based on naturally given dimensions of thier individual fibre elements.

3.2 Fibre boards

A selected number of fibrous raw materials was used for investigations on the suitability of different types of binding agents. Intermediates based on wet preservation have not been evaluated only in pure form but have been mixed with other raw materials e.g. wood for certain experiments as well (Fig. 9).

Boards with densities ≤ 650 kg m^{-3} (according EN 622-1 ultra-light and light MDF) are showing the lowest values of bending strength. They do not meet the requirements for dry process boards (MDF) for general use at 25 MPa.

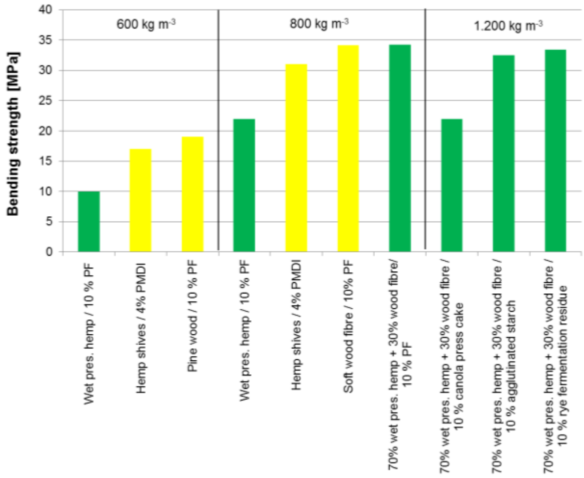

Fig. 9: Density related bending strength of fibre board samples from different raw materials

Boards consisting of a mixture of wet preserved hemp and wood fibres and pressed with phenolic formaldehyde resin (PF) to higher densities achieve mechanical properties above this level. Also bio-based glues can be used to produce high quality composites but only at higher densities. PMDI (Polymeric Methylene Diphenylene Diisocyanate) is increasingly used in the panel industry and enables the production of high quality boards based on hemp shives as well.

A further experiment was carried out in order to compare the common raw material wood fibre with fibres resulting from wet preservation at similar process conditions. Boards have been prepared without and with the same adhesive (phenolic formaldehyde resin - PF) and pressed at densities of approximately 1.200 kg m^{-3} (Fig. 10).

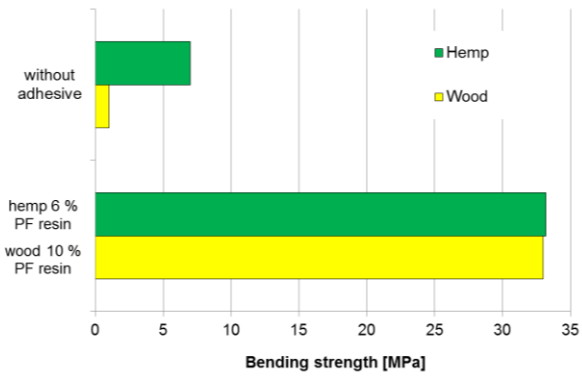

Fig. 10: Bending strength of fibre board samples from wood and wet preserved hemp fibres

The results show that the replacement of wood by hemp fibres enables the reduction of required adhesive by 4 % resulting in similar specimen properties. Furthermore the values of bending strength of hemp samples compared to wood fibres are significantly higher when pressed without a binding agent.

3.3 Mineral bond blocks

Up to now only tentative tests for the utilization of wet preserved raw materials, extruded as well as milled fibrous intermediate a reinforcing or filling agent were carried out. It became clear that semi-manual mixing with a stirrer leads not at any time to homogenous bulk useful for the formation of “green blocks”. Still remaining fibre agglomerates considerably influence the even distribution in the form and finally the quality of test specimens.

The related specimen characterization was adapted from other materials and respective test procedures. The actual splitting tension test according EN 1338 did not result in reasonable results. Therefore traditional compression strength test have been carried out at Zwick-Roell test center (Fig. 11 left). Force peaks of 47 … 96 kN at compression of 9 … 38 mm have been recorded.

Fig. 11: Test setups for the characterization of block specimens based on mineral bond wet preserved hemp fibres

ATB`s material test machine Zwick-Roell Z010 ProLine equipped with a respective test setup was used for further tests on bending strength (Fig. 11 right).

Two different raw material qualities have been used to reinforce the mineral matrix:

- A by-product from traditional hemp straw processing which is consisting of app. 50 % short fibres and 50 % small particles from the woody core of the stalk (shives)
- Fibres processed from wet preserved hemp

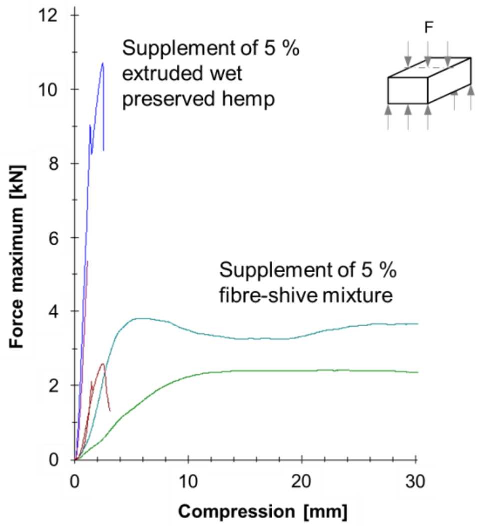

Fig.12: Mechanical properties of test specimens filled with different hemp base raw materials

A considerable higher value of compression has been recorded when the fibre-shive mixture was added to the mixture. The utilization of processed wet preserved hemp is resulting in a lower compressability but a significant higher force maximum.

4 CONCLUSIONS AND SUMMARY

An alternative supply chain for bast fibre crops as a raw material for the manufacture of fibre boards and for the reinforcement of mineral building materials has been developed and practically realized for hemp. The harvesting and storage procedure is similar to the production of animal fodder and does not require specialized machines or facilities. The procedure risk is lower compared to the traditional dry straw based on field/dew retting as the whole crop material is removed from the field directly with the harvest operation. Famers are enabled to take value from the excellent characteristics of hemp as preceding crop in a rotation.

The procedure for the subsequent processing of the whole crop material allows the integration and/or mixture with other biomass in order to ensure optimal intermediate and final product qualities. The properties can be further influenced by several operational parameters of the defibration with the extruder and the disc mill. Results of respective experiments with the novel raw material from wet preserved hemp as well mixtures with other biomasses have shown that wet-preserved hemp can be processed to high quality HDF and MDF boards. Both synthetic and bio-based binder agents are suitable for such applications. The replacement of wood by wet preserved hemp or mixtures thereof can enable the reduction of crude oil based raw materials in the fibre board industry.

Furthermore wet preserved raw or processed hemp can be used as filler or reinforcement for mineral building materials. The naturally content of moisture (unchanged from harvest to mixture) could be beneficial for on-site application in some situations. An advantageous characteristic of wet preserved hemp is the decomposition of almost all sugar components as a result of microbiological activities in course of wet preservation. Based on first preliminary results it can be concluded that better recipes in combination with improved procedure steps of mixing, specimen formation will be necessary to develop mineral building products fitting in typical application requirements. Furthermore test procedures and respective devices have to be improved and adapted as well.

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