Developments in the use of fibres from wet-preserved hemp for composite production

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Abstract: A weather-independent procedure for the supply and processing of wet-preserved fibre plants is under investigation at the Leibniz Institute for Agricultural Engineering (ATB) for several years. In the pilot plant, set up in 2007, the effect of raw material, operation, and construction parameters on the fibre quality has been examined. At the Technical University Chemnitz, the suitability and reinforcement effect of preserved hemp fibre in composites was tested. Initial results have shown that the strength and stiffness of polypropylene-composites can be clearly improved using preserved hemp fibres.

Keywords: hemp, wet preservation, composite, natural fibre, Germany

Citation: Gesine Wallot, Hans-Jörg Gusovius, Ralf Pecenka, Stefan Schierl, Roman Rinberg, and Wolfgang Nendel. 2012. Developments in the use of fibres from wet-preserved hemp for composite production. Agric Eng Int: CIGR Journal, 14(4): 218−223.

1 Introduction

In the past 30 years, the growing, processing, and utilizing of natural fibres have gained in significance. In 2005, for example, the German automotive industry used about 19,000 t of natural fibres (not including wood and cotton fibres) for composites with polymeric matrix (Karus et al., 2006). From an ecologic point of view, natural fibres offer an interesting alternative compared to the conventionally used glass and carbon fibres. Technological advantages also result from the low abrasive properties in processing, the low material density, and the respective potential for light-weight construction as well as the positive shatter properties in composites. Moreover, natural fibres like flax and hemp show substantial reinforcement potential in composites, since they have comparable specific Young’s moduli as glass fibre (Bledzki and Gasssan, 1999).

Besides, for farmers the cultivation of natural fibre plants like hemp represents an alternative crop and alternative source of income. Cropping hemp is advantageous because it does not require the use of any plant protection (Desanlis, 2006). Furthermore, including hemp in crop rotation has a positive effect. Studies have shown that following crops produce up to 30% higher yields (FNR, 1997).

However, other than synthetic fibres, natural fibres show a significantly higher variation in their mechanical properties (Summerscales et al., 2010). Key reasons for that are varying weather conditions during growth and at the time of harvest. Following steps of decortication respectively processing of the raw fibre material – as well as the further processing into composites also often cause damage to the fibre, which has an impact on the composite properties (Bledzki et al., 2007; Hughes, 2012). The reinforcing effect of natural fibres in injection

Received date: 2012-06-06 **Accepted date:** 2012-11-13
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moulded parts is significantly determined by the fibre properties and the fibre geometry. There, the fibre fineness and the length to width ratio (aspect ratio) are of special significance (Ruth et al., 2002; Specht, 2007). The strength and stiffness of the composite increase with growing aspect ratio (Stark and Rowlands, 2003; Schirp and Stender, 2010).

The quality and morphology of the fibre are influenced by growth and weather conditions as well as by the respective processes. The traditional generation of natural fibre raw materials from flax and hemp is based on field drying and retting as well as the subsequent mechanical separation into fibre and non fibre components. The weather during this phase of harvest is commonly not predictable and can lead to very inhomogeneous quality of the raw material, or even to total loss of the crop. In past years, the Leibniz Institute for Agricultural Engineering Potsdam Bornim e.V. (ATB) developed an innovative method for the supply and processing of wet-preserved hemp and other fibre materials to provide required fibre quality. At present, the research at ATB focuses on the optimization of the quality of this new type of fibre material by purposeful adaptation of the processing plant design and operation parameters for processing. In addition, the Technical University Chemnitz has carried out first examinations about processability and reinforcing effects of these fibres in composites.

2 New method for provision and processing of fibre plants

The method for supply and processing of fibre plants is based on preserved storage of such fibre plants and the subsequent processing into fibre materials. The significant advantage of the new process technology compared to the traditional harvest of fibre plants (on-field drying and retting) lies in the reduction of the weather-related processing risk in harvest and supply. Moreover, the agricultural areas are made available faster for next field preparation and sowing in the crop rotation.

Harvesting is carried out with a conventional field chopper. Subsequently, the chaff is compressed in silage bags, and stored anaerobically (Forschungsbericht ATB, 2003; Pecenka et al., 2007). At that, the complete plant material including leaves and seeds is used. The so-called preserved hemp can be taken from the silage stock on demand and supplied to a special mechanical processing procedure. The material is run through a two-stage defibration and milling process, mainly facilitating a defibration extruder and a disc mill. After drying, the generated fibre material can be further processed into fibre boards (Gusovius et al., 2009). A pilot plant with a raw material input of up to 1 t h^{-1} (300 kg h^{-1} DM) for realization of this new process chain was installed at ATB in 2006 (Figure 1) and has been validated and further developed since.

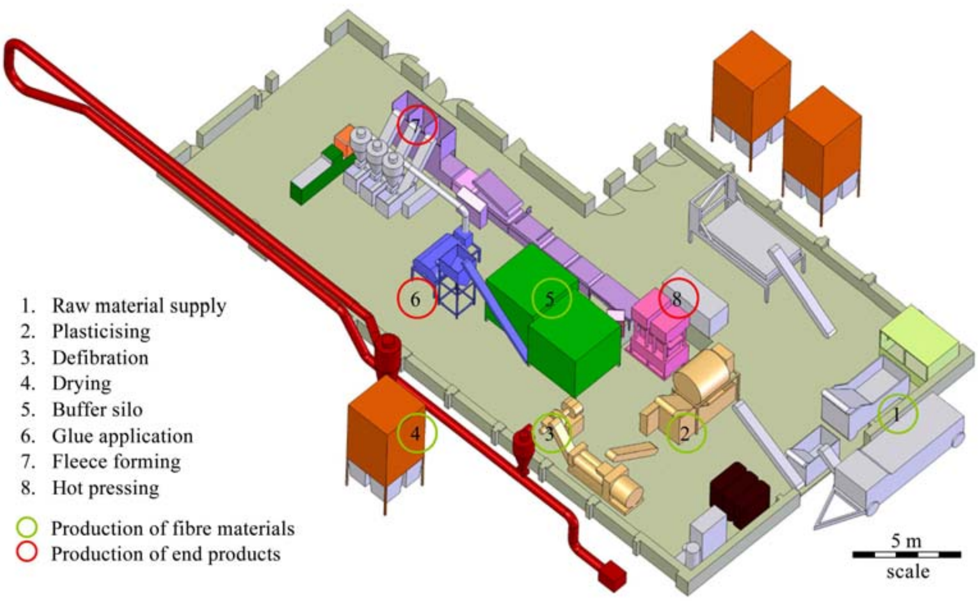


Figure 1 Pilot plant for processing of fibre plants

2.1 Defibration process

The first stage of the processing procedure is carried out with a defibration extruder. This extruder is fitted with two counter-rotating horizontal screw shafts. The material in the threads between the screw shafts is exposed to continuously changing pressure, as well as high shear and friction forces, leading to defibration of the fibre structure. Due to the friction, the temperature significantly increases during the process, which positively influences defibration (Cong et al., 2006). The fibre material leaves the process, heated to 90℃, as an agglomerated fibrous material (Figure 2).

Figure 2 Wet extruder fibre material (left) and dried fibre material after milling in extruder and disc mill (right)

In order to increase the degree of defibration, the fibre is fed into a disc mill after being processed by the extruder. Here, the plasticisation of the fibre material due to the exposure to heat in the extruding process, has a positive influence on further defibration (Cong et al., 2006). In this process, a disc mill equipped with a static disc and a rotating disc, is operated under atmospheric pressure. The disc diameter is 20 inch (50.8 cm). Between the discs, the fibre is exposed to shearing and compression. Furthermore, friction is caused by the interaction of the fibres, and interaction of the fibre with the surface of the milling disc. The processing through the disc mill causes a separation of the extruder agglomerated fibres. The exposure to these forces leads to a reduction of fibre width, and normally to a shortening of the fibre. By subsequent drying in a stream dryer, the material is further separated but also gains in volume (Figure 2).

The selection of material, operation, and construction parameters allows a variation of the defibration effect in the disc mill. Current research has shown that the quality of the fibre material is determined by the type and the dry matter content of the used raw material. Operation conditions and mill disc geometry only had an insignificant influence on the milling result (Wallot et al., 2011).

3 Materials and methods

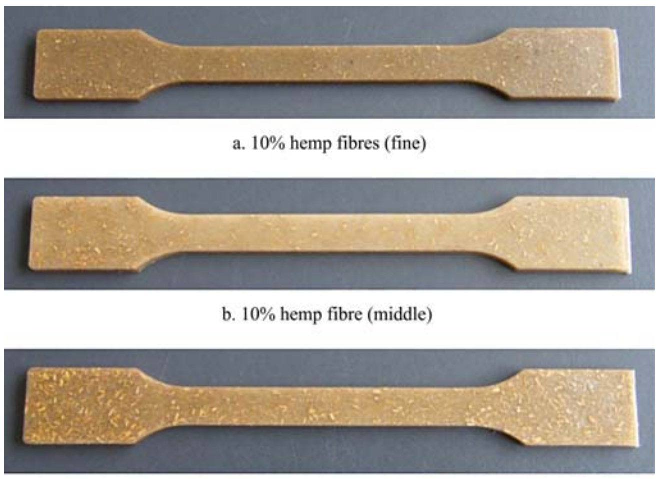
3.1 Raw materials

Anaerobically stored hemp was mixed with 30% wood chips (pine wood), processed in above described two stage defibration procedure, and subsequently dried. Additional milling of the material in a cutting mill and additional fractionating of resulting material (Table 1) was deployed to accommodate an improved dosing of the fibre material on compounding with the polymer material.

Table 1 Aspect ratio and length-weighted 50th percentile of the fibre length/width of the tested hemp fibre fractions

Fibre quality	Aspect-Ratio/-	x_{50}-Length/μm	x_{50}-Width/μm
Fin	11.3	1690	63
Middle	8.3	3340	74
Coarse	4.6	4690	119

The processing of the fibre into granulated material was facilitated in the dual-screw-compounder Noris Plastic ZSC 25/44D. Test rods (Figure 3) from the compound materials were made in a KraussMaffei MM-80-380CX injection moulding machine. The matrix material used in all tests was Polymer Domolen P2600M (DOMO® chemicals) with 3% coupling agent. The mass proportion of the added fibre was 10% and 20% respectively.



a. 10% hemp fibres (fine)

b. 10% hemp fibre (middle)

c. 20% hemp fibre (coarse)

Figure 3 Test rods made of PP with

3.2 Methods of analysis

3.2.1 Fibre analysis

Primary fibre properties of the raw materials prior to and directly after removal from storage were evaluated by the cooperation partner Faserinstitut Bremen. This was related to mechanical as well as geometrical parameters. The fibre strength in cN tex^{-1} was measured with a Stelometer on 20 fibre bundle collectives separated by a coarse opener. The fibre fineness was assessed by indirect measuring of airflow through a fibre flake, using an FMT-Shirley respectively airflow device.

The characterization of the fibre morphology was evaluated by particle size analysis with the image analysis program FibreShape©. Geometric parameters like aspect ratio and the length-weighted 50^{th} percentile of the fibre length/width were calculated from the generated particle size distribution.

3.2.2 Analysis of mechanical properties of composite test bodies (mechanical testing)

The tensile properties of the test rods were measured according to DIN EN ISO 527 using a Zwick Roell Z100v tensile testing machine. A fixture length of 115 mm, a measuring length of 50 mm, and a test speed of 10 mm min^{-1} were applied. The test rods' dimensions were 170 × 10 × 4 mm. Bending tests were carried out with the same testing machine according to DIN EN ISO 178. The span width was 64 mm and the test speed was 2 mm min^{-1}. The test bodies measured 80 × 10 × 4 mm. The impact resistance according to Charpy was measured according to DIN EN ISO 179-2 on the instrumented RESIL IMPACTOR pendulum. The test bodies were identical to those from the bending strength test.

4 Results

4.1 Fibre morphology

By class, the used preserved hemp fibres were separated in three fractions (fine, middle, coarse). The analysis of the fibre morphology for the single fractions showed respectively clear differences in the geometrical parameters (Table 1). The fine fraction was found with the highest aspect ratio at 11.3, and also had the lowest fibre width. The aspect ratio of the coarse fraction was clearly smaller. The fractions were not only different in their geometric properties, but also in their dosability in the compounder. The fine and coarse fraction could be dosed trouble free using the standard dosing unit of the compounder, while there were tremendous problems in dosing the middle fraction, due to the high amount of very fine and relative long fibres.

4.2 Fibre fineness and fibre strength of hemp chaff

The fineness and fibre strength for wet preserved hemp chaff was evaluated dependent on storage time. It became clear that the anaerobe storage process has a significant impact on the fibre fineness and strength (Figure 4). With longer storage time, the fineness increased due to reduction of fibre gluing substances like pectines. On the other hand, the fibre strength of fibre bundle collectives declined to about half in a 12 month period.

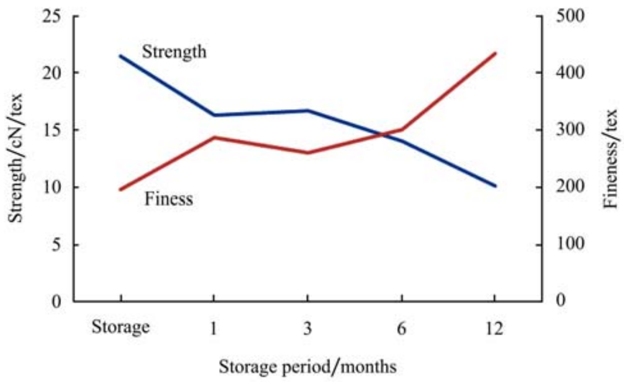


Figure 4 Fibre strength and fineness of fibre bundle collectives from preserved hemp in dependence of storage time

4.3 Preserved hemp fibre in composites

The research has shown that the addition of fibre from anaerobe storage processes can lead to improvement of the quality parameters of the composite.

4.3.1 Influence of fibre proportion

The mechanical parameters of the composites with a proportion of 10 and 20 weight-% preserved hemp fibres of the fine fraction are shown in Figure 4. With an increase in fibre proportion there was an increase of the respective Young's moduli determined (Figure 5). Tensile strength and flexural strength showed similar tendencies (Figure 5).

So far tests have also shown, however, that achieving high impact strength when using natural fibre remains a challenge. The impact strength sank drastically with increasing fibre content (Figure 6). Although the decline of these parameters can be reduced by using impact strength optimized matrix polymers, the limiting influence of the natural fibre still remains.

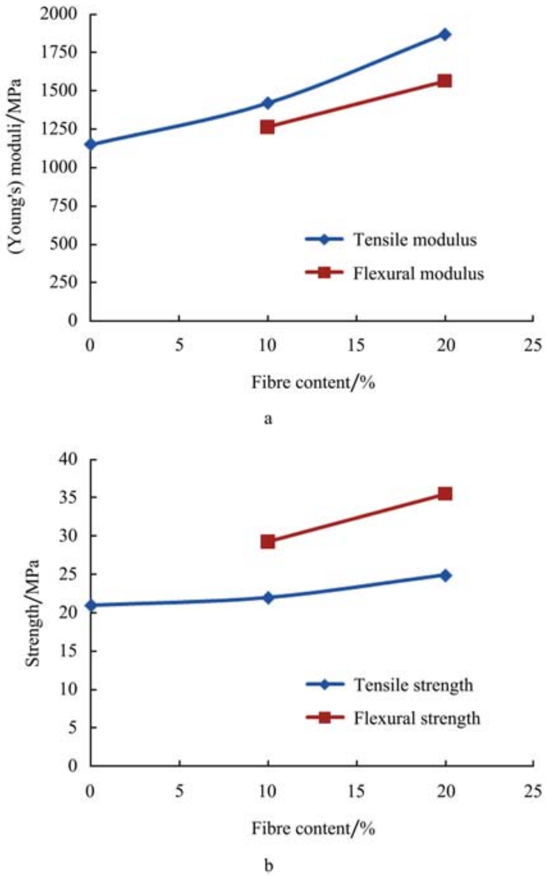


Figure 5 Tensile and flexural (Young's) moduli (a) and tensile and flexural strength (b) of composites from polypropylene and preserved hemp fibre (fine fraction) in different weight proportions

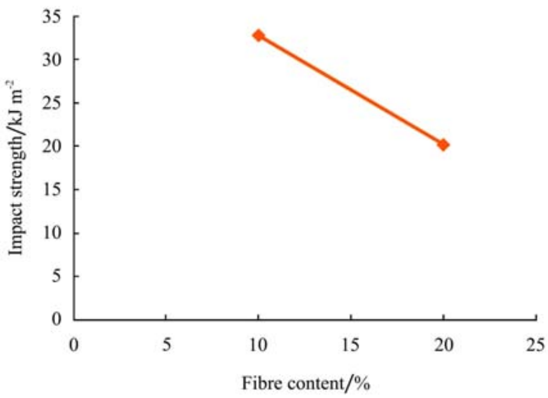


Figure 6 Impact strength of composites from polypropylene and preserved hemp fibres (fine fraction) in different weight proportions

4.3.2 Impact of fibre morphology

It was shown that the fibre morphology also had an impact on the mechanical properties of the fibre reinforced composites. Adding finer fibre led to higher values in Young's moduli and tensile and flexural strength than adding coarser fibre fractions. The main reason is the higher fineness and the higher aspect ratio of the fibre of the fine fraction compared to those of the coarse fraction (Table 1).

4.3.3 Comparison of reinforcing effect of conventional hemp fibres and preserved hemp fibres

The comparison with fibres from the conventional, dry supply chain process showed that the potential for reinforcement in composites is not negatively impacted by preservation storage. The elasticity (Young's) moduli for both types of fibre achieved a similar level (Figure 7). Thus, the decline in tensile strength measured in the fibre bundle collective test with preserved fibres (Figure 4) can be considered to play a secondary role in polymer composites. This leads to the conclusion that during preservation storage a decline in fibre gluing substances between the single fibre cells occurs due to enzyme activities of micro-organisms, but the single fibre cell is not affected. Accordingly, only the binding strength between the fibre bundles or single fibres decline.

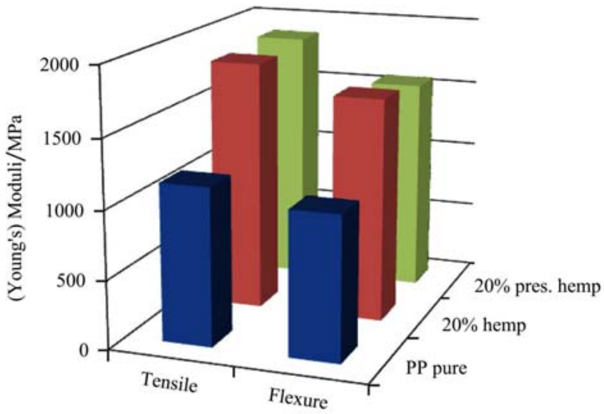


Figure 7 Tensile and flexural (Young's) moduli for reinforced composites from PP and preserved hemp fibres or hemp fibres from dry decortication

5 Conclusion

Research has established that fibres from the new method for supply and processing of wet preserved fibre plants are generally suitable for the use in composites. The strength and stiffness of PP-composites can be clearly improved by using preserved hemp fibres. The dosing of the fibre by respective feeders into the compounder is feasible within certain parameters, however, it requires optimization. Research is currently continuing in this area. Eventually, besides an improvement of the mechanical properties by using preserved fibre, the fairly low and reasonable costs for the fibre are an interesting aspect for future applications in composites. Based on the current price development of hemp fibres from dry decortication, the use of preserved hemp fibre could reduce the price by 50%.

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