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HEMP FINES - AN AGRICULTURAL BY-PRODUCT FOR BIOCOMPOSITES? A HOLISTIC APPROACH

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ABSTRACT

The technical, environmental and economic potential of hemp fines as a natural filler in bioplastics to produce biocomposites is the subject of this study – giving a holistic overview. Hemp fines are an agricultural by-product of the hemp fibres and shives production. Shives and fibres are for example used in the paper, animal bedding or composite area. About 15 to 20 wt.-% per kg hemp straw results in hemp fines after processing. In 2010 about 11,439 metric tons of hemp fines were produced in Europe. Hemp fines are an inhomogeneous material which includes hemp dust, shives and fibre. For these examinations the hemp fines are sieved in a further step with a tumbler sieving machine to obtain more specified fractions. The untreated hemp fines (ex work) as well as the sieved fractions are combined with a polylactide polymer (PLA) using a co-rotating twin screw extruder to produce biocomposites with different hemp fine content. By using an injection moulding machine standard test bars are produced to conduct several material tests. The Young’s modulus is increased and the impact strength reduced by hemp fines. With a content of above 15 wt.-% hemp fines are also improving the environmental (global warming potential) and economic performance in comparison to pure PLA.

KEYWORDS

Hemp, fines, polylactide, biocomposite, life cycle assessment, economic.

INTRODUCTION

In an era of increasing material demand and a society driven by climate change the use of bast fibre plants as a sustainable and environmental impact reducing material has become the focus of research groups around the world. Bast fibre plants build their own group in the class of natural fibre plants - they are characterized by a bundeled bast fibre part around the stem and a wooden core part also called shive (Müssig 2010). One representative of this group is hemp. So far the main research focus has been on the fibre component of the hemp plant due to its superior properties compared to the other plant components. Recently also the shive component has been considered in research (Faruk et al. 2012, Matina et al. 2011). But bast fibre plants like hemp have beside the fibre and shive components also a fine component which results from the processing of the plants. In 2010 the processed hemp straw in Europe resulted in 25,589 metric tons of fibres, 43,621 metric tons of shive as well as 11,439 metric tons of fines. The fine fraction makes up to 15 to 20 wt.-% after processing and thereby is a notable part of the hemp production. Currently the fine fraction is just used for low value adding applications e.g. incineration or use as low quality animal bedding compared to hemp shive (European Industrial Hemp Association 2013). One possible value adding application area is the field of biocomposites. Therefore the use of hemp fines for biocomposites was studied from a holistic perspective taking into account the technical, environmental and economic impacts. The hemp fines were used without further treatment (ex work) as well as in sieved fractions.

MATERIALS AND METHODS

Materials

The matrix polymer is a polylactide (PLA) with tradename Natureworks 3251 (NatureWorks LLC), which is designed for injection moulding applications. The hemp fines were obtained from BaFa neu GmbH and used ex work as well as in further sieved fractions.

Methods

Technical

The fibre characterization is conducted with the fibre analysis software Fibre- and Powdershape (IST - Innovative Sintering Technologies Ltd.). For further processing of the hemp fines (ex work) in more homogenous fractions a tumbling sieving machine (Allgaier Werke GmbH) is used. The biocomposites are compounded without prior drying using a twin screw extruder (ZE 34 basic from Krauss Maffei Berstorf GmbH), see Figure 1.

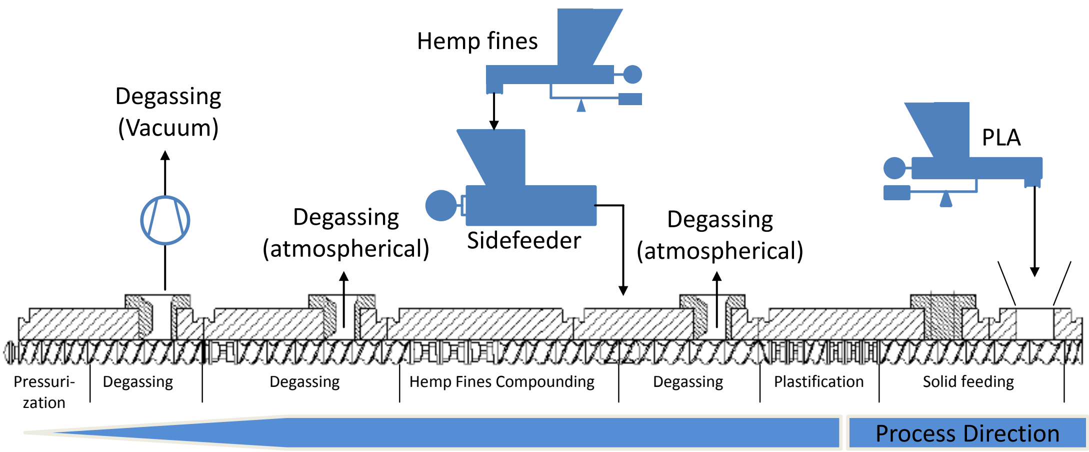

Figure 1. Process scheme: compounding via co-rotating twin screw extruder

The PLA matrix was melted first, and then the hemp fines were added via a twin screw side feeder into molten PLA in the middle process area. The dosage of materials was done gravimetrically; varying from 15 to 40 wt.-% (dry mass) of hemp fines. Figure 1 shows the processing procedure of compounding. The sufficient possibility of an efficient degassing is very important for the extrusion of water-containing materials; it can be guaranteed by the use of a co-rotating twin screw extruder (Kohlgrüber et al. 2008). The used configuration has a total of three degassing zones. Following the compounding was a 4-hole round nozzle. After water cooling granules were produced for injection molding using a granulator. The production of test bars (1A) is conducted via injection moulding (50-180AX from Krauss Maffei Technologies GmbH) after pre-drying of the material at 80 °C for 12 h. Previous to the material characterization the test bars were conditioned at 23 °C and 50 % relative humidity for 7 days after moulding. To characterize the biocomposites Young's modulus (ISO 527) and Impact Strength (ISO 8256) were determined.

Environmental

The environmental performance of the biocomposites in comparison with pure PLA was determined by life cycle assessment according to ISO 14040/44 with the life cycle assessment software GaBi6 (PE International AG) using background data from Ecoinvent and GaBi for materials as well as the process steps (GaBi 2014, Ecoinvent 2014). The performance is analyzed for the partial life cycle "Cradle-to-Gate" including the material production phase with a functional unit of 1kg material, taking into account the biogenic carbon uptake by photosynthesis as proposed by Patel et al. (2013). The methodology CML 2001 - April 2013 is used for impact assessment with focus on the global warming potential other impact categories relevant for biocomposites like acidification potential, eutrophication potential, photochemical ozone creation potential, ozone depletion potential and abiotic depletion (Endres et al. 2011) are not calculated in this first approach. As there is currently no life cycle inventory data for hemp fines available an average value for hemp fibres and hemp shive was used as a first estimation.

Economic

The economic performance of the biocomposites in comparison with pure PLA was determined with average prices for materials and process steps obtained from several industry stakeholders to give a first overview on the price impact of hemp fines. Also the cost for the additional process step of extrusion is considered, while the sieving process step was neglected due to non-available information. The functional unit is chosen analogue to the approach for the environmental performance calculation.

RESULTS AND DISCUSSIONS

Hemp Fine Sieving and Characterisation

Pre-trials with hemp fines (ex work) showed that the larger fibre as well as the larger shive components caused some problems in the compounding process by winding around the side feeder screws, which were negligible during trials but might cause problems on an industrial scale. Therefore a further sieving process step was used to classify the hemp fines (ex work) in 5 fractions, see Table 1.

Table 1. Fractionized hemp fines

Fraction	Picture	Mesh (mm)	Share of hemp fines (ex work) (wt.-%)
F1		>5	8.7
F2		3.15-5	4.9
F3		1.25-3.15	23.7
F4		0.6-1.25	19.1
F5		<0.6	43.6

The challenging components for compounding (larger fibres and shives) got separated in the fractions F1 and F2. Therefore only the fractions F3 to F5 were used for additional trials beside hemp fines (ex work) .These fractions have also the main share of the sieved hemp fines (ex work) with 86.4 wt.-% (F3: 23.7 wt.-%; F4: 19.1 wt.-% and F5: 43.6 wt.-%). Nevertheless fractions F1 and F2 can easily be fed in the existing hemp fibre and shive value chains and therefore contribute to the economic amortization of an additional sieving process step to obtain the fractioned hemp fines. In addition the sieving into fractions allowed a more specific look at the hemp fines. The analysis of the fractions F3 to F5 was conducted to determine the aspect ratios: F3: 5.2; F4: 3.9; F5: 2.9.

Technical Performance

Young's modulus

The Young's modulus of the different biocomposites is shown in Figure 2. Hemp fines are increasing the Young's modulus compared to pure PLA. With increasing hemp fine content also the Young's modulus is increasing. Such an influence is shown for hemp fines (ex work) as well as fraction F5.

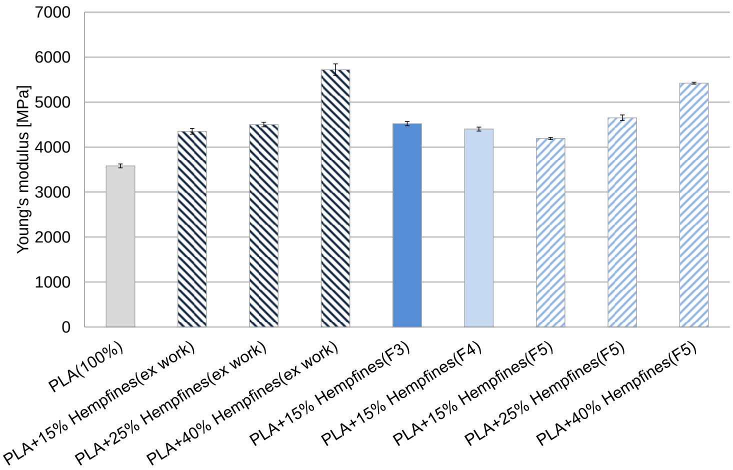

Figure 2. Young's modulus in MPa

The difference between the different hemp fine fractions (F3 to F5) as well as the hemp fines ex work is for 15 wt.-% in a range of 4190 MPa (F5) to 4520 MPa (F3). The fraction with the highest aspect ratio (F3 with 5.3) results also in the highest Young's modulus value.

Impact strength

The influence on the impact strength is shown in Figure 3. In comparison to pure PLA the impact strength is reduced significantly from 17.32 kJ/m ²to an average of 6.5 kJ/m ²by 62 %.

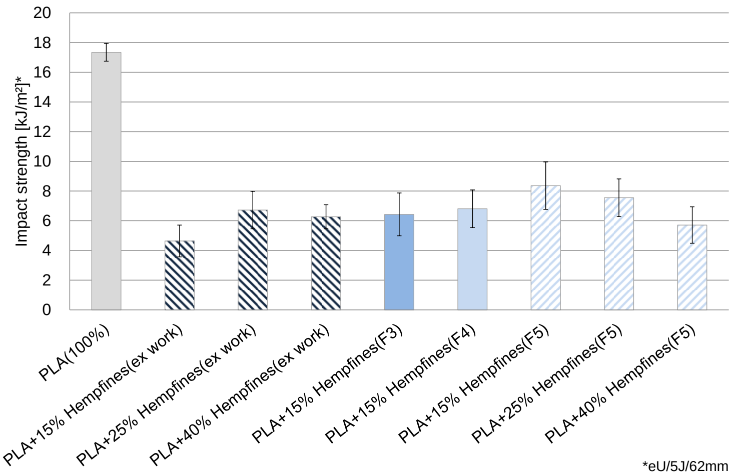

Figure 3. Impact strength in [kJ/m²]

With increasing hemp fine content the impact strength is decreasing, with respect to fraction F5. A similar trend is not shown by the hemp fines ex work and probably caused by the larger shive pieces which act as a breaking point. Comparing the influence of the fine fractions (F3 to F5) the impact strength of the fraction with the lowest aspect ratio (F5) is higher than the one of the fraction with the highest aspect ratio (F3). This is indicating that the smaller particles of fraction F5 can absorb more energy during the impact test. Such an impact on the properties was also reported by (Mukherjee et al. 2011) for natural fibres.

Environmental and Economic Performance

The environmental performance of the biocomposites with hemp fines in comparison to pure PLA with focus on Global Warming Potential (GWP) was calculated for PLA with 15 wt.-%, 25 wt.-% and 40 wt.-% hemp fines (average values for all fractions based on hemp fibres and shives). The calculation was conducted for GWP including the biogenic carbon uptake by photosynthesis, see Figure 4.

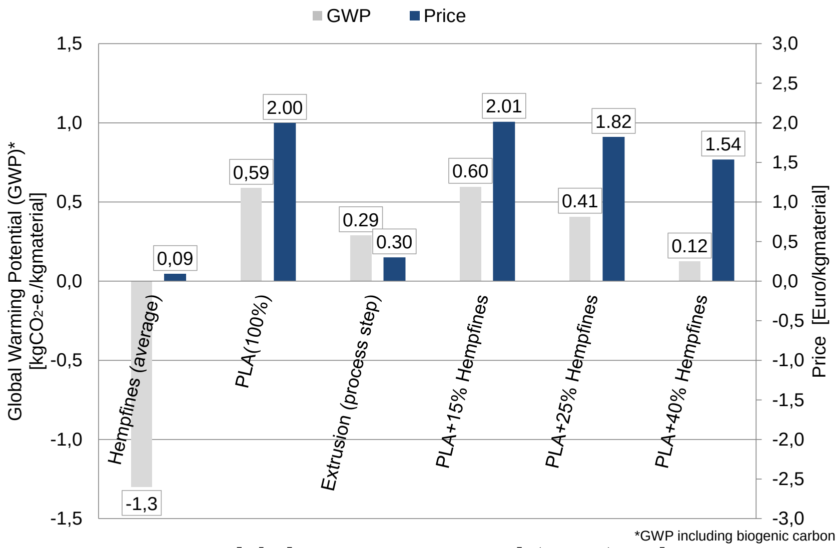

Figure 4. Global Warming Potential (GWP) and Price

The hemp fines (average value) have with -1.3 kgCO_2-e./kg a smaller (negative) GWP in comparison to PLA with 0.59 kgCO_2-e./kg. Nevertheless there is no positive influence of creating PLA-hemp fine composites with just 15 wt.-% hemp fines. The reason therefore is the additional process step to combine PLA with hemp fines (extrusion) which causes an additional environmental impact (0.29 kgCO2-e./kg). Just with a higher hemp fine content it is possible to overcome these additional impacts. With a content of 40 wt.-% hemp fines the GWP can be reduced from 0.59 kgCO_2-e./kg material to 0.14 kgCO_2-e./kg material by 76 %. This shows the possibilities of hemp fines to further reduce the GWP of bioplastics like PLA on a cradle to gate perspective. The negative GWP of hemp fines is caused by the uptake of biogenic carbon by photosynthesis and the low impact of its processing compared to PLA. The processing of PLA is more complex and thereby having a higher impact (Groot and Borén 2010). To complement the holistic approach undertaken for hemp fines as a material for biocomposites also the economic performance of PLA-hemp fine biocomposites in comparison to pure PLA was determined in a first estimation. With a price of 90 €/t for hemp fines compared to 2,000 €/t for PLA, the hemp fines have a price advantage of around 96 %. In Figure 4 the calculated price of pure PLA per kg in comparison to PLA with 15 wt.-%, 25 wt.-% and 40 wt.-% is shown. Although the price of hemp fines is significantly lower than the PLA one the use of just 15 wt.-% hemp fines causes a higher price of 0.01 €/kg. This increase of price is caused by the additional process step of combining the PLA with the hemp fines (extrusion). The cost for this additional process step is taken in account with 0.3 €/kg. Increasing the hemp fine content above 15 wt.-% causes a reduction of the overall price below the price of pure PLA. With 25 wt.-% the price is decreased from 2.0 €/kg to 1.82 €/kg by 9 %. 40 wt.-% of hemp fines reduce the price by 23 % to 1.54 €/kg. Although an additional process step is necessary for the production of PLA-hemp fine biocomposites the price can be reduced by hemp fines if the content is increased to >15 wt.-%.

CONCLUSIONS

Hemp fines (ex work and fractioned) are suitable for PLA biocomposites up to a content of 40 wt.-% with the currently used processing equipment. The fine fractions can be used to improve material properties like Young's modulus but are also decreasing properties like impact or tensile strength. Above a content of 15 wt.-% in the PLA biocomposites hemp fines are also improving the environmental as well as the economic performance. Below 15 wt.-% the additional compounding process via twin-screw extrusion is compensating these economic and environmental benefits of the addition of hemp fines. The further treatment of hemp fines via sieving can remove hemp fine components like the long fibres or shive pieces that might cause challenges on an industrial scaled process. In addition the sieving step produces more homogenous hemp fine fractions which might allow slightly more specific applications. The study has shown the potential of hemp fines in the area of biocomposites and highlighted possible benefits and challenges from a holistic perspective. Further research will focus on the optimization of the sieving process step. Another critical aspect is the determination of sand content of the different hemp fine fraction to avoid problems with abrasion during a possible later scale up. With scale up and identification of suitable applications the collection of life cycle inventory data for hemp fines is necessary to determine its exact environmental impact.

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