Utilization of hemp (*Cannabis sativa* L.) as an alternative raw material for the production of three-layered particleboard

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Abstract. As the availability of high quality trees decreased and the price increased the wood base panel industry is looking to replace the common used wood by agricultural residues or fast growing trees and plants as well as agricultural plants like hemp (*Cannabis sativa* L.). Hemp offers characteristics that are similar to wood properties. In line with this research, three-layered particleboards under utilization of hemp material were developed. The hemp was used in combination with industrial produced particles to find out which amount of wood can be substituted by hemp and further to investigate which decreased densities can be realized by the use of hemp. Hemp can be used for the production of lightweight particleboards due to its lower bulk density compared to wood. All developed hemp/wood based particleboards were produced under industrial parameters in laboratory and pilot scale using conventional urea formaldehyde-resin, hardeners, and hydrophobic substances. The mechanical technological properties of all produced innovative particleboards and reference particleboards were determined according to current DIN/EN standards. In detail density profile, bending strength, internal bond strength, surface strength, and thickness swelling were determined. Compared to the produced reference particleboards, consisting only of wood particles, the developed hemp/wood particleboards possessed better mechanical-technological properties. Furthermore it was realized to produce particleboards with densities of 550 kg/m³ by using hemp due to its low bulk density which fulfills the given DIN/EN requirements. As an overall result we found out that hemp is a real alternative to nowadays used wood for the production of particleboards in general and for the production of lightweight particleboards in particular.
Keywords: Hemp, wood, particleboard

Introduction

Particleboards are currently made by wood residues that occur during the production of lumber and plywood. Nevertheless there are further opportunities to utilize post-consumer as well wood waste and paper waste as well as agricultural residues as raw materials for the production of wood based panels. Not only agricultural waste can be utilized to substitute wood as material for the production of particleboards; also fast growing plants like hemp (*Cannabis sativa* L.) offer a potential to substitute the common wood. Hemp belongs to the family *Cannabinaceae* (genus *Cannabis* species *sativa*). Hemp is a race of *C.sativa* that has low levels of DELTA9-tetrahydrocannabinol (THC), the psychoactive constituent of marijuana, and higher levels of cannabidiol (CBD). THC levels lower than 0.3% cannot produce any psychoactive effects (Grotenhermen, *et al*., 1998). Nevertheless because of the presence of even very little amounts of THC in hemp, this plant was under the control of government. By the time, there was a new progression in many countries that had banned hemp changing their laws to legalize it again because they look more benefit can obtain from industrial hemp due to its uses. Most developed countries that permit hemp cultivation require the use of varieties with less than 0.3 percent THC (Vantreese, 1998).

The interest to utilize hemp is to refer the shortage and increasing price of biomass, particularly wood, because of a transition from fossil resources to renewable resources. That makes a fast growing, high-yielding and mechanically strong plant such as hemp interesting for many applications. Ranalli (1999) describes that hemp stems can be separated into two main components: the stem tissues outside the vascular cambium (bark) and the stem tissues inside the vascular cambium (core). Bark and core differ in their chemical composition. Bedetti and Ciaralli (1976) in Ranalli (1999) reported 67% cellulose, 13% hemicelluloses and 4% lignin in the bark of an Italian hemp cultivar. Its core contained 38% cellulose, 31% hemicelluloses, and 18% lignin.

While the conservation of wood and forest stands is of main importance throughout the whole world, the development of hemp-based particleboards is an interesting alternative to protect the forests. This board has emerged as a versatile substitute for wood in a wide range of applications. Moreover these boards can also be made decorative with elegant looks by fit in colors and, therefore, can be more attractive than any wood/plywood substitute.

Using hemp as a substitute for the common used wood can lead to innovative products; so called lightweight building boards.

In line with this research, the utilization of hemp as well as single material as well as substitute in combination with industrial wood particles for the production of three-layered particleboards will be analyzed. As a substitute pure hemp will be used in the middle layer and also mixed with industrial wood particles in different proportions. Pure industrial wood particles will only be used in the surface layer. The main aim is to investigate the technical suitability of hemp as a raw material for lightweight particleboard products, by considering the technical properties of the developed product, the process properties and the properties of hemp.

Materials and Methods

Materials

Materials that used for the production of three-layered wood / hemp particleboards in laboratory scale are industrial particles that were produced at the Pfleiderer Holzwerkstoffe GmbH & Co in Gütersloh and hemp chips produced at the company Nordhanf Gmbh, Rosenow. As a binder urea-formaldehyde resin was used and an additional material such as "HydroWax 138" (hydrophobic substance) was used. Furthermore 33% Ammoniumsulfat solution was used as hardening accelerator combined with the urea-formaldehyde resin.

Production of three-layered particleboards in pilot-scale

Particleboards in different densities and different ratios concerning the used materials hemp and industrial produced particles were developed in line with this research. All of these particleboards were produced in laboratory scale. Pure fine industrial particles were used for the surface layer while a mixture of industrial particles combined with hemp was used for the middle layer. For comparability, the reference boards consisting only of industrial produced surface and middle layer particles were produced in the same densities. The following densities were produced: 350 kg/m^3, 450 kg/m^3, and 550 kg/m^3 with a pressing time of 3 minutes what is equal to a press factor of 9 seconds per mm thickness for a 20 mm particleboard. All variants were made in three-time repetition and the average values concerning the mechanical-technological properties were calculated out of all produced boards for one variety.

Table 1 Varieties of examined particleboards

Variant	Board Type
I	0 % Hemp , 100 % Wood in SL & ML
II	25 % Hemp % , 75 % Wood in ML & 100 % Wood in SL
III	50 % Hemp , 50 % Wood in ML & 100 % Wood in SL
IV	75% Hemp , 25 % Wood in ML & 100 % Wood in SL
V	100 % Hemp , 0 % Wood in ML & 100 % Wood in SL

ML = Middle Layer , SL = Surface Layer

Determining the mechanical-technological properties

The mechanical technological properties of all produced innovative particleboards and reference particleboards were determined according to current DIN/EN standards. In detail bending strength, internal bond strength, surface strength, and thickness swelling were determined.

Results and Discussion

The data that is obtained will be compared to the standard minimum requirements for particleboards with a thickness of 13 mm up to 20 mm (Germany Institute of Standard e.V., 2003) regarding to mechanical and technological properties including density profile, bending strength (MOR), internal bond strength (IB), surface strength, and thickness swelling. Those minimum requirements are presented in Table 2.

Table 2 Standard minimum requirements for particleboards according to DIN/EN (Germany Institute of Standard e.V., 2003)

Norm	Bending Strength (N/mm^2)	Internal Bonding Strength (N/mm^2)	Surface Strength (N/mm^2)	Swelling (%) (after 24 h)
P 1	11.5	0.24	-	-
P 2	13.0	0.35	0.8	-
P 4	15.0	0.35	-	15

Which:
P 1 = Requirements for particleboards related to general purposes for the use in dry areas, P 2 = Requirements for particleboards related to interior furnishings for the use in dry areas, P 4 = Requirements for particleboards board related to load-bearing purposes for the use in dry areas

Density profile

The density of a wooden material is defined as the ratio of the mass of each specimen related to its volume in kg/m^3. As a result all variants reached the target densities of 450 kg $/m^3$ and 550 kg $/m^3$. By using the density analyzer device, it is possible to produce diagrams of the vertical density profile (VDP). This profile resembles a U-shape, with the peak density near the board surfaces, and the lowest density in the core (Wong, *et al*., 1999). It is occurs due to the hot pressing process results in an uneven density distribution along the thickness direction of the board. The three-layer board showed typical U-profile of density due to fine particles on the panel surfaces. The fine particles were easy to press at a high temperature and formed a higher density (Kelly, 1977). Figure 1 represents the density profile and average density of a particleboard with a density of 350 kg $/m^3$ (variant III). The average density is 376.97 kg $/m^3$.

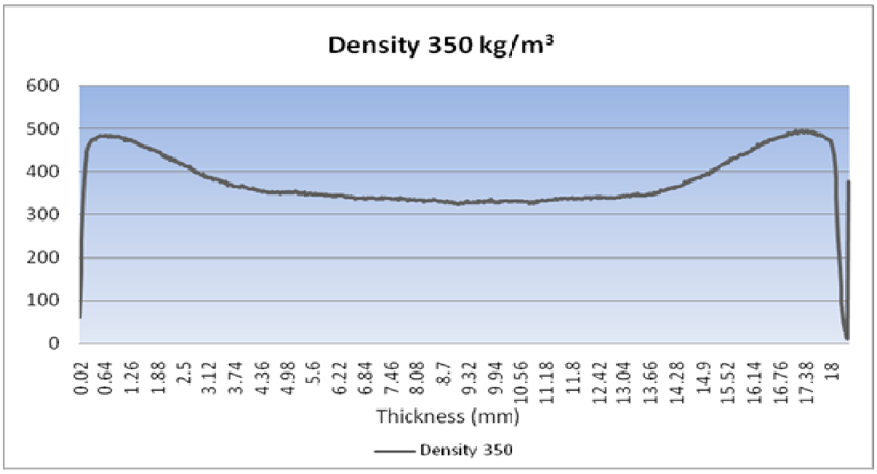

Figure 1. Density profile of a produced particleboard

The compression in the surface layer is higher than in the middle layer because of the different particle sizes (fine/coarse), intersperse quantity, particle moisture, and glue ratio. The different densities between surface and middle layer cause a planking effect to particleboards which gives the particleboard endurance power.

Bending strength

The bending strength of particleboards is measured for static bending. Based on the test, the bending strength also rises by increasing the bulk density. However, according to

DIN/EN 312-P2 that requires a minimum value of 13 N/mm² all variants does not fulfill the standard. Only the board from variant V with a density of 550 kg/m^3 (the highest strength 11.79 N/mm^2) is corresponding to the standard DIN/EN 312-P1 which required a minimum value of 11.5 N/mm^2. The raw density plays a central role for the meaning of all strength properties of wood materials. The density of the board is an important index of strength. In general, boards of higher density feature higher strength properties but the relationship is not linear (it depends on the type of board and the manner of loading). Wood density is also important; for a given board density wood of lower density will lead to boards with higher strength. The reason for this is that a given weight contains more particles of a lighter wood and during the pressing process the contact between these particles is better (Tsoumis, 1991). The bulk density of the hemp boards is lower than the bulk density of the reference boards; therefore the hemp boards have a larger volume so that the hemp chips in the manufacturing process must be pressed more densely together than wood particles.

Internal bond strength

Internal bond strength is commonly testing of tensile strength perpendicular to the board surface. By this test method the layer with the lowest coherence is determined. Based on the test the internal bond strength increases by an increasing density. However, according to DIN/EN 312-P2, that requires a minimum value of 0.35N/mm², all hemp board variants with densities of 450 kg/m³ and 550 kg/m³ fulfill the standard value. The highest strength was determined in variant V with 0.68 N/mm^2 at a density of 550 kg/m^3. At a density of 350 kg/m³ only the standard for DIN/EN 312-P1, that requires a minimum value of 0.24 N/mm²; is fulfilled. Therefore the pressing time of 3 minutes is sufficient to obtain standard values concerning the internal bonding strength for hemp mix with industrial particles in the middle layer. The internal bond strength of hemp boards is higher compared to the reference boards because hemp features a larger volume due to a lower bulk density. When pressing the hemp material the strength is increased due to higher material quantities. The high proportion of dust and fine material in chips, particularly in the surface layer material, possibly affected the strength of particleboards made of hemp or wood particles. The proportion of fine material in hemp chips is less compared to industrial middle layer particles, which makes the glue separate well. Vos (2005) also mentioned if the amount of dust and fine material is to low the glue will be easily separated in the chips and it will increase the strength.

Surface strength

This test is focused on the surface layer area and gives information about the resistance of the surface layer. Based on the test the surface strength is increased by increasing the density. As a result, all examined boards with a density of 550 kg/m^3 reached the standard value of DIN/EN 312-P2. It is observed that the highest value (1.32 N/mm^2) is reached by variant IV with a density of 550 kg/m³. Compared to internal bond values the surface strength values are higher. A three-layer particleboard consists of the central layer (core) and two outer layers (faces). The structures of these layers differ significantly. The faces are made of smaller particles whose resin content and compaction ratio are higher. As a result they have a bigger density, stiffness and strength. Weakness of the surface layers was probably due to squeezing the adhesive with water vapor movement in the surface mats (Korai *et al*., 1999).

Thickness swelling

Based on the test, the thickness swelling after immerse in water for 24 hours increases as well as with increasing density. As a result, all examined boards with a density of 350 kg/m^3 reached the standard value of DIN/EN 312–P4 (maximum value is 15 %). At densities of 450 kg/m^3 and 550 kg/m^3 only variant II reached the standard value. The lowest swelling was found in variant I with 10.15 % at a density of 350 kg/m^3. Thickness swelling is perhaps the most important factor when considering moisture effects. It can be affected by most process variables such as wood species, particle geometry, board density, resin level, blending efficiency, and pressing conditions (Halligan, 1970). The thickness swelling values of particleboards produced from a mixture of hemp and industrial particles were very poor. This is based on the less percentage using a hydrophobic substance in the production of boards. As a consequence, the boards require additional treatments such as the coating of particleboard surfaces with melamine-impregnated papers or laminates or high press temperature usage to become a more stable product (Nemli, 2000).

Conclusions

The manufacture of three layered particleboards from hemp chips (*cannabis sativa* L) in various proportions with industrial wood particles in the middle layer is a possibility to develop lightweight boards. Furthermore it was realized to produce particleboards with densities of 550 kg/m³ by using hemp due to its low bulk density which fulfills the given DIN/EN requirements for particleboards related to interior furnishings for the use in dry areas. The manufacturing done by using hardener, water proof agent and urea formaldehyde as binder with 3 minutes pressing time.

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