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STRAW PULP AS A SECONDARY LIGNOCELLULOSIC RAW MATERIAL AND ITS IMPACT ON PROPERTIES OF INSULATING FIBERBOARDS

PART I. CHARACTERISTIC OF STRAW FIBRE FROM THE PERSPECTIVE OF THE MASS CREATION

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ABSTRACT

The article describes the impact of the addition of straw pulp as a partial replacement of softwood pulp in the preparation of insulating fiberboard (IFB) on its properties. Part I. discusses about the preparation of straw pulp from wheat straw and the characterization of the fractional composition of the fiber, determining the amount of water held by fiber, dewatering rate and determining of grade of defibrillation. Insulation straw boards were prepared from the fibre exactly characterized. Strength properties - tensile strength and flexural strength perpendicular to the face (internal bond strength) and physical properties - swelling and water absorption were tested on boards prepared.

KEYWORDS: Straw insulating fiberboards, characteristic of pulp, fiber distribution according Brecht-Holl, insulation board's preparation, properties of insulation boards.

INTRODUCTION

A substitution of coniferous wood fiber used in the manufacture of insulating fibreboards by secondary raw materials can be an important factor to increase the competitiveness of the manufacturing enterprises. The possibility of replacing wood in the manufacture of fibreboards by other material must result from the similarity of some properties and chemical composition of coniferous wood properties and chemical composition of the material mentioned. Mass creation processes in IFB are based on the use of physico-chemical and chemical bonds and last but not least the mechanical forces of interlaced fibers without the use of adhesives. Van der Waals forces and hydrogen bonds are applied to stabilize and increase the strength of interlaced fibers of emerging board.

Hydrogen bond strength is around 10 % of the force of a covalent bond (Gažo 1981), but the number of hydrogen bonds is significantly higher. Possibility of covalent bonds creation in the manufacture of IFB arises due to a releasing of the wood structure by opening of middle lamellas. Lignin plasticization in middle lamellas by temperature of about 160°C and use of mechanical power for a chips disintegration and generate radicals which can subsequently react into a formation of covalent bonds among the individual fibers. Radicals generated by thermal and mechanical degradation of the primary bonds and also by thermal activation of double bonds and some lignin end groups enter into binding (Fig. 1).

Increase of that effect can be achieved by an enzyme- phenol oxidase, which causes the creation of more stable radicals in the lignin. The radicals also produce covalent bonds among the fibers and thus increase the strength of the formed fiber board (Claus and Felbia 2004).

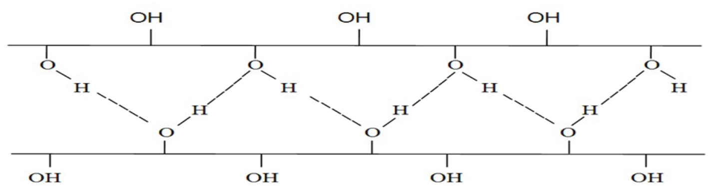

Fig. 1: Hydrogen bonds among cellulose chains.

It is therefore important that replacement fiber is capable of entering into contact with the wood fibers and generate the same or similar chemical bonds. From this point of view monocots plants (family *Poaceae*), such as cereals, appear as replacement. Straws as well as wood contain parenchyma and sclerenchyma tissues. Vessels of some plants are also circularly reinforced; the difference is in the position of elements in the cross section of plants and trees (Požgaj et al. 1997). Also, the chemical composition of the stalk is favorable; the lignin content determined using the TGA is 7 % higher than for spruce (Kádárová 2004). The older literature suggests 16-21 % of lignin content for the straw compared to 26.9 % for wood of spruce and 20.9 % for beech (Hamilton et al. 1987).

Agglomerated materials based on flax, hemp and bagasse are produce worldwide from stalks of plants of the family *Poaceae*. Also insulating materials from the entire wheat straw are manufactured under the different trade names, e.g. Stramit. Great attention was paid to research of wood particles substitution with particles of these residues. It was an effort to create a medium-density particleboard (Mo et al. 2003), respectively a low density particleboard (Wang and Sun 2002) or to find a suitable use of this material, for example sound absorbing construction (Yang et al. 2003). Fiber boards are also produced from rice straw. Cereal straw after chemical treatment is used for a paper production (Youngquist et al. 1994). It can be stated that the stalks of cereals (wheat straw) in terms of tissue and chemical composition are similar to timber. As reported by Reddy and Yang (2005) lingocellulosic agricultural byproducts are a copious and cheap source for cellulose fibers.

In addition to the similarities, it is necessary that the secondary material is available in reasonable quantities for use in the production. It is obvious that the use of wheat straw has a real potential for a successful application in the manufacture of IFB as partial compensation of fiber from coniferous wood. The amount of pulp substituted is resulting from physical-mechanical and thermal properties of the resulting fiberboard with a straw pulp, respectively straw fiberboard if 100% of straw pulp is used for its production. The aim of this work is to characterize the straw fiber and check the conditions of its use in the preparation straw insulation fiberboards (SIFB).

MATERIAL AND METHODS

Wheat straw was chopped in a cutter mill MN 300/400 for the size of 30-50 mm. Chopped straw was washed before refining through a drainage sieve to remove dust particles and warmed in the water at temperature of 90°C. Laboratory straw refining was carried out on hot refiners at 90°C through 2, 4 and 6 mm width of a milling gap.

The particles thus obtained were further processed using a pulper Sproud-Waldron 12 "in terms and conditions:

Laboratory disc refiner Sproud-Waldron 12 ":

- Mill has fibrillation blade
- Operating speed – 890 RPM
- Engine power - 28 kW
- Milling gap - adjustable in the range of 0-30 mm
- Cutting angle - 30 °
- Angle of the blade - 15 °
- Ls (second edge blade's length) - 0.623 km. s^{-1}

The fiber obtained was characterized by a fractionation. The fiber fractionation was performed on a Brecht Holl classifier according to STN 50 0289 (1984). Fiber was also characterized by drainage time, amount of water and defibering degrees (DD). Defibering degrees reflect the time of dewatering of 128 g of pulp in 10 liters of water. Distribution of fibers for each DD values was measured three times. Straw insulating fiberboards (SIFB) with density of 250 kg .m^{-3} were prepared on a laboratory line Defibrator AB. Physic-mechanical properties as density, bending strength, internal bond strength, swelling and water absorption were determined according to relevant standards STN EN 622-4 (2000), STN EN 310 (1998), STN EN 319 (1995) and STN EN 317 (1995) for samples prepared and conditioned at conditions t = 20°C, φ= 65 %.

RESULTS AND DISCUSSION

Characteristics of the straw pulp

Distribution of the straw pulp prepared was compared to the values of the distribution of wood fiber from the production of fiberboards with density of 250 kg.m^{-3}. It is expected that if we reach similar values, we will be able to prepare SIFB with similar features like IFB.

Distribution of fibers depends on the degree of straw refining (Tab. 1). Straw fiber with DD about 15 has a high amount (about 30 %) of chips and just only 19 % of long fibres. Ratio of fine fibers (mesh 240 and above) is set at 15 %. Thus grinded straw fiber has a good dewatering level similar as a wood fiber which was producing in the factory Smrečina Hofatex, Slovakia. Increasing of the fineness level on DD 45 degrees has significantly increases the proportion of long fibers to around 51 %. Portion of chips is reduced to 12 %. Both of these changes are significant in terms of physic-mechanical properties of the prepared plates of SIFB.

Long fibers and chips partially also determine a structure and strength of a boards due to mechanical action of intertwined long fibers. Fines fibers increase the strength of the matrix of long fibers by linking with long fibers using physical and chemical bonds finely shredded particles. Therefore, the presence of about 19 % of fine fibers has a significantly positive effect on the final physical and mechanical properties of fiberboards. Comparing the distribution of fibers according to Brecht-Holla straw pulp with DD at 40 to 45 seconds and the distribution of wood fiber produced in the manufacture IFB with DD = 38 seconds, chips in straw pulp represent 12 % compared to 7.76 % in wood fiber (Tab. 1). It is higher by 55 %. Others values of distribution of straw fibers and wood fibers produced in Smrečina Hofatex are at the same level.

Tab. 1: Properties of the straw fibers prepared in laboratory scale and the refined wood fibers produced in Smrecina Hofatext, Slovakia (250 kg.m^{-3}).

Sample		Straw pulp							Wood pulp
		DD-14	DD-15	DD-16	DD-41	DD-45	DD-73	DD-68	DD-38
Dewatering (seconds)	500 ml	4.08	6.33	8.42	22.08	24.10	33.89	34.57	6.00
	700 ml	14.20	18.83	29.96	59.52	69.70	102.36	99.50	13.80
	800 ml	29.57	32.16	57.30	103.10	117.84	185.63	166.24	23.27
Brecht – Holl (%)	chips	35.41	28.66	38.35	12.19	13.12	8.31	7.51	7.76
	+16 (mesh 40)	21.02	19.03	17.87	51.36	50.57	51.23	46.44	52.41
	+50 (mesh 120)	27.80	35.34	29.85	19.03	15.65	13.45	10.26	19.47
	+100 (mesh 240)	8.27	7.50	7.88	10.09	6.98	4.59	6.39	5.41
	-100 (above mesh 240)	7.50	9.46	6.05	7.34	13.70	22.42	29.41	12.95
WRV (%)		135.20	128.46	139.01	149.23	152.96	153.19	154.12	95.70

Further increasing of straw refining on DD 73 leads to a positive reduction of percentage amount of chips to 8.3 %. It causes a stable amount of long fibers at 51 % and an increasing of fine fibers at 26-36 %. Curve of the percentage of particles decreases by DD growing. The amount of long fibers grows just until DD around 40 degrees (Fig. 2). Representation of fine straw fibers varies in the range from 15 up to 36 %. A high percentage of fine fibers worsen the dewatering process within the preparation of plates. Amount of short fibers (mesh 120) was reduced from 35 % for milling at 15 DD up to 10 % for the DD 68. Increased percentage of short fibers has no positive effect on mass creation processes.

Time of dewatering of straw fibers significantly increased with DD grades growth (Tab. 1). When time of dewatering of 800 ml of water is 32 seconds at DD 15, it is 185 seconds at DD 73. Drainage time for the same amount of mentioned fiber dewatering is 23 seconds at DD 38, which is 5.2 times less than the value of 119 seconds reached for the straw fiber at DD 45 degrees.

The reason for this is probably in greater fibrillation of walls of straw pulp. Higher requirements for drainage of fiber mat in operational production of straw insulation fiberboards to achieve the desired dry weight of the mat are the consequence of it or needs to create the mat from wood and straw fibers with an optimal representation of both types.

Important is the fact of higher percentage of water collected (WRV) by straw pulp compared to wood pulp (Tab. 1). Straw fiber captures 150 % of water regarding to dry straw mass while wood fibers capture about 95 % of the dry weight of wood fibers. This is caused by differences in the structures of fibres. Straw stalk structure has higher porosity than structure of wood fiber. Higher level of water absorbency of fiberboards with a straw pulp compared to IFB is the consequence of this fact.

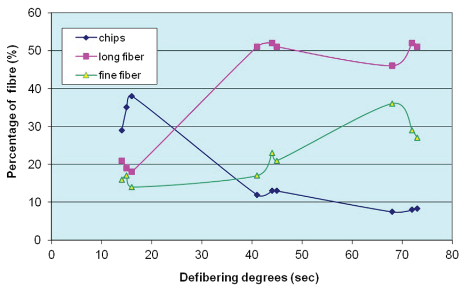

Fig. 2: Distribution of straw fibers according to Brecht-Holl prepared in laboratory conditions depending on the degree of grinding.

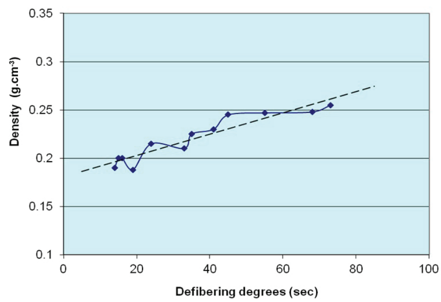

Fig. 3: Straw insulating fiberboards (SIFB). Dependence of a density of SIFB on defibering degrees (DD).

Physic-mechanical properties of laboratory prepared SIFB

An evaluation of the physic-mechanical properties of fiber natural materials is based on the molecular composition and structure of the fibers. Straw is considered as itself composite material, comprising cellulose microfibrils bound within an amorphous matrix of lignin and hemicelulose (Hornsby et al. 1997). Many authors attach an important role in strength to lignin. Lignin is a highly crosslinked molecular complex with amorphous structure and acts as glue between individual cells and between the fibrils forming the cell wall (Mohanty et al. 2000). Lignin is first formed between neighboring cells in a “middle lamella,” bonding them tightly into a tissue, and then spreads into the cell wall penetrating the hemicelluloses and bonding the cellulose fibrils (Majumdar and Chanda 2001). Lignin provides plant tissue and individual fibers with compressive strength and stiffens the cell wall of the fibers to protect the carbohydrates from chemical and physical damage (Saheb and Jog 1999). The lignin content of the fibers influences the structure, properties, morphology, flexibility and rate of hydrolysis. The elasticity of the fiber is important property for physic- mechanical properties as well. Fibers with higher lignin content appear finer and will be more flexible (Sukumaran et al. 2001). Generally, fibers with a lower amount of cellulose have higher lignin content. Lignin can range from water soluble (lignosulfonates) to insoluble (kraft lignin) even in general organic solvents such as acetone.

This analysis of fiber properties showed the dependence of the fiber distribution on defibering degrees of grinded fiber (DD). This implies a dependence of physic-mechanical properties of straw insulation fiberboards on DD (Tab. 2). Physic- mechanical properties of boards for each DD were assumed relative to the same density of 250 kg.m^{-3} due a given dependence of physic-mechanical properties of the density of insulation boards and physic-mechanical properties. Various densities of insulation boards were created due different level of grinding on different

DD (Fig. 3). The different distribution of fiber is connected with this fact. Cushion of boards (an increasing of the thickness of the plate after release a pressing pressure) with higher amount of chips (lower DD) is higher than for boards with lower amount of chips (higher DD). The cushion causes a lower density and higher thickness of the insulating board.

A flexural strength of boards growths with DD increasing (Tab. 2). Increase of the bending strength higher for lower values of DD than for higher DD. The growth of flexural strength has a very moderate increment when the value DD 45-55 is achieved (Fig. 4). Flexural strength of low density fiberboards according to STN EN 622-4 (2000) has a minimum value of 0.8 MPa. This strength of straw is achieved with fiber refined at lowest grades.

Tab. 2: Flexural strength and strength in tension perpendicular to the surface of the SIFB in dependence on defibering degrees.

Defibering degrees DD (sec)	**Density ($g.cm^{-3}$)**	**Flexural strength (MPa)**	**Strength in tension perpendicular to the surface (kPa)**	**Flexural strength converted on relative flexural strength of board with density of 250 $kg.m^{-3}$ (MPa)**	**Strength in tension perpendicular to surface converted on relative flexural strength of board with density of 250 $kg.m^{-3}$ (kPa)**
14	0.190	0.78	14.0	1.02	18.4
15	0.200	0.84	17.0	1.05	21.2
16	0.200	1.06	20.0	1.32	25.0
19	0.188	1.25	29.0	1.66	38.5
24	0.215	1.78	40.0	2.06	46.5
33	0.210	1.61	38.1	1.92	45.3
35	0.225	2.16	50.5	2.40	56.1
41	0.230	2.12	48.9	2.30	53.1
45	0.245	2.30	54.0	2.35	55.1
55	0.247	2.44	63.2	2.47	63.9
68	0.248	2.53	63.3	2.55	63.8
73	0.255	2.74	67.6	2.68	66.2

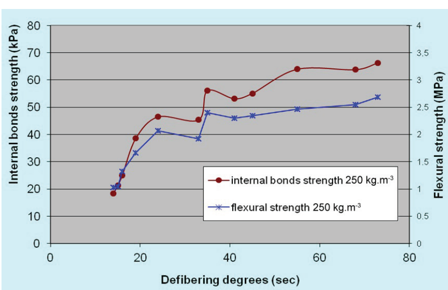

Fig. 4: Flexural strength and strength in tension perpendicular to surface of ISFB converted on relative strengths of a board with density of 250 $kg.m^{-3}$ in dependence on defibering degrees (DD).

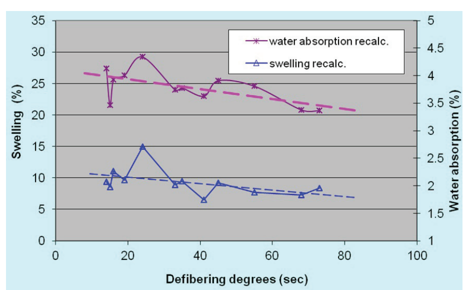

Fig. 5: Swelling after 2 hour, water absorption after 2 hours SIFB in dependence on defibering degrees (DD).

Strength in tension perpendicular to the surface (internal bond strength) has a similar course of dependence DD as it is in the case of flexural strength (Fig. 4.). The increment of increasing strength is only minimal at DD 45-55 and above.

Tab. 3: Swelling after 2 hours and water absorption after 2 hours of straw insulating fiberboards in dependence on defibering degrees (DD).

Defibering degrees DD (sec)	Density ($g.cm^{-3}$)	Swelling after 2 hours (%)	Water absorption after 2 hours (%)	Swelling converted on relative swelling of board with density of 250 $kg.m^{-3}$ (%)	Water absorption converted on relative water absorption of board with density of 250 $kg.m^{-3}$ (%)
14	0.190	2.73	36.0	2.07	27.3
15	0.200	2.47	27.0	1.97	21.6
16	0.200	2.83	32.0	2.26	25.6
19	0.188	2.79	35.0	2.09	26.3
24	0.215	3.15	34.0	2.70	29.2
33	0.210	2.40	28.6	2.01	24.0
35	0.225	2.31	27.0	2.07	24.3
41	0.230	1.90	25.0	1.74	23.0
45	0.245	2.10	26.0	2.06	25.5
55	0.247	1.60	24.9	1.58	24.6
68	0.248	1.85	21.0	1.84	20.8
73	0.255	1.92	20.3	1.95	20.7

The course of both curves is in very good conformity. Progress of swelling and water absorbance have similar course. Minimum value of strength perpendicular to the surface (internal bonds) is 50 kPa which is specified by the IFB manufacturer. These values are achieved within refining of straw-fiber at over 35 defibering degrees for SIFB. Achieved values of flexural strength and strength perpendicular to the surface meet the requirements of STN EN 622-4 (2000) and manufacturer of fiberboards with a density of 250 $kg.m^{-3}$. Physical property, swelling after 2 hours, is improved but just slightly with growth of defibering degrees (Fig. 5). Swelling values are very low. The swelling values at higher DD are less than half of values of the STN EN 622-4, (2000). Also the values are smaller than maximum values specified by manufacturer for IFB with a density of 250 $kg.m^{-3}$.

Water absorption after 2 hours of laboratory prepared SIFB decreases slightly with growing DD. Decreasing of an amount of chips and an increasing proportion of fine fibers decreases absorption of SIFB just a little. Significantly higher values of water absorbency of SIFB in compare to IFB is caused by differences in the anatomical structure of coniferous wood and straw stubble. Macroscopically, conifers include tracheids with thick cell walls arranged in regular rows, that the cross-section contains only a small lumen. Straw contains two major xylem vessels and one or two vessels of smaller size. The vessels on their cross-section appear as holes. Cross section is formed as concentric rings leaving a void or lumen in the centre (Hornsby et al. 1997). Vessels of straw except transpiration stream have a mechanical function. The vessels are surrounded by sclarenchymatic mesh. It follows that straw has a larger internal volume than wood for the unit weight of straw or wood. Value of amount of water captured by straw is 1.6 times higher than captured by wood. Value of water absorbency of SIFB with DD 45 divided by that number is 13.75 % which is value of water absorbency usually achieved in IFB. The fact that, despite the high value of water absorption of SIFB, a value of swelling at the same or lower level than of IFB with 13 % water absorption should be taken into account. From this can be concluded that the values of water absorption of straw insulation fiberboards (from 22 to 25 %) are natural values resulting from the anatomy of straw. These values have no influence to worse other characteristics of SIFB.

CONCLUSIONS

Following conclusion from the preparation and characterization of straw insulation fiberboards prepared in laboratory conditions can be stated:

- Conclusions from the analysis of straw fiber, that fiberboards prepared of straw pulp have properties on the level of wood based fiberboards and meet manufacturer's requirements for IFB production when defibering degree DD 40 or more is reached, have been confirmed.
- Straw insulation fiberboards prepared in the laboratory scale have a flexural strength, strength perpendicular to the surface and swelling at the same level as IFB and comply with STN EN 622-4 (2000) and manufacturer's requirements.
- Increased water absorption for straw insulation fiberboards is natural and it is caused by different anatomical structure of the straw stalk and has not a negative impact on other properties.
- Time of dewatering of straw pulp is 5.2 times longer than for wood based boards. Adjustment of technology for the dewatering process in the production needs to be assumed to reach mat moisture as required. To create mat of fibers with an optimal representation of both types of fibers is the second option for the production.

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