WOOD RESEARCH
60 (3): 2015
441-450

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

PART III. PREPARATION OF INSULATING FIBERBOARDS FROM SEPARATELY MILLED LIGNOCELLULOSIC RAW MATERIALS.

Vladimír Ihnát
Slovak Forest Products Research Institute
Bratislava, Slovak Republic

Vlastimil Borůvka, Marian Babiak
Czech University of Life Sciences
Prague, Czech Republic

Henrich Lübke, Jiří Schwartz
Slovak Pulp and Paper Research Institute
Bratislava, Slovak Republic

(Received April 2015)

ABSTRACT

Effect of the addition of straw pulp as a partial replacement of coniferous wood pulp in the preparation of insulating fiberboards (IFB) on its properties is described in the work. A preparation of straw pulp from wheat straw and its characterization with the subsequent laboratory preparation of straw insulating fibreboards (SIFB) has been described in Part I. A preparation of mixed pulp prepared by jointly grinding of straw and wood pulp for the required percentage content is described in Part II. A preparation of fibers obtained by a separate milling of wood particles and straw in pilot conditions and their mixing for a desired ratio of wood and straw pulp is described in Part III. The pulp is characterized by a fractional composition of fiber length, determining the water retention value (WRV), dewatering rate and defibering degrees (DD). Strength properties - flexural strength and tensile strength perpendicular to the face (internal bond strength) and physical properties - swelling and water absorption were determined for prepared plates. A coefficient of thermal conductivity was determined as well.

KEYWORDS: Wood- straw insulating fiberboards, characteristics of pulp, fiber distribution according Brecht-Holl, preparation and properties of insulating boards, coefficient of thermal conductivity.

INTRODUCTION

Research of wood particles substitution by straw in boards was provided with the aim 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). A possibility to replace wood by other material in the manufacture of fiberboards must arise from a similarity of some properties and chemical composition (Han 1998; Youngquist et al. 1994; Felby et al. 2004). The role of lignin was discussed also (Hornsby et al. 1997, Mohanty et al. 2000, Majumdar and Chanda, 2001, Saheb and Jog, 1999, Sukumaran et al. 2001). Board's creating processes during the uncompressed IFB production are based on the utilisation of physic-chemical and chemical bonds and not least the mechanical forces of interlocking fibers (Lübke et al. 2014). An ability of the replacement of fiber entering into a contact with the wood fibers and forming the same or similar chemical bonds is therefore important. From this point of view monocots plants (family Poaceae), belonging to cereals, appear as a proper replacement.

The volume of replaced wood pulp influences on the physic-mechanical and thermal properties of the resulting IFB with straw content. An addition of straw pulp affects mentioned properties, as stated in Part II. (Ihnát et al. 2015). The common grinding of wood chips and chopped straw causes increased amount of residual fine fibers, which increases the bulk density of the insulating boards over the desired value. It also causes the deterioration of dewatering ability of pulp and the coefficient of thermal conductivity also. In turn, it improves their mechanical properties. For these reasons, straw pulp was prepared separately so the density of 250 $kg.m^{-3}$ was reached when added to the wood pulp.

The aim of this paper is to determine the properties of pulp obtained by a separate grinding of wood chips and chopped straw and properties of pulp obtained by mixing wood fibers and straw pulp in the range from 0 to 100 % and determine their properties as well.

MATERIAL AND METHODS

Refined wood pulp was taken from the IFB production line in Smrečina Hofatex, Inc. Banská Bystrica (Slovakia). The refining of wood fiber was provided thermo-mechanically by a disc refiner RGP 32 DEFIBRATOR under operating conditions for the production of wood pulp. The refiner is equipped with a milling set with 13° cutting angle with second cutting edge length Ls=139 $km.s^{-1}$ at 980 RPM with an efficient energy consumption of 98 $kWh.t^{-1}$.

Straw was chopped by a cutter mill MN 300/400 to the size 30-50 mm. A semi production milling was provided by the mill Jylhä 0 with KU blades (14° cutting angle) and with the second length of cutting edges of Ls=13.53 $km.s^{-1}$ at 950 RPM using of 30 kW motor.

The wood pulp and the straw pulp were characterized by a fractionation. The fiber fractionation was performed on a fractional device by Brecht-Holl according to STN 500289 (1984). The fibers were also characterized by a dewatering rate, the amount of retained water (WRV) and defibering degrees (DD). Defibering degrees reflect the dewatering time of 128 g fibers in 10 liters of water. The fiber distribution for various values of DD was measured three times.

IFB with a density of 250 kg.m^{-3} were prepared on a pilot line (DEFIBRATOR AB) which consists of a holander, dewatering equipment, pre-press and a current oven. IFB were prepared with 0, 5, 10, 15, 20, 30, 50, 80, a 100 % content of straw pulp.

The calculated amount of wet refined wood fiber and the calculated amount of refined straw pulp is soaked in water to form a suspension with 1.5 % of the dry matter and mixed thoroughly. Calculated quantities of additives- 4 % of starch emulsion (8 % of starch), 1.5 % in paraffin wax emulsion (6 % of wax) and 0.73 % of aluminium sulphate (7 % water emulsion) are added in Valley holander and mixed.

The aqueous suspension is transferred to a dewatering machine. The board is cold-pressed after the dewatering. A drying was carried out in a convection oven at 160°C for 3 to 5 hours depending on the specific weight of the board.

Physic and mechanical properties- the density, flexural strength, tensile strength perpendicular to the board, swelling and water absorption were tested according to the relevant standards STN EN - 622-4 (2000), 310 (1998), 319 (1995) and 317 (1995) at prepared boards under laboratory conditions (t=20°C, φ=65 %).

Thermal properties of the insulating boards were determined on a coefficient of thermal conductivity base. The coefficient of thermal conductivity (λ) was measured using ISOMET. The measured samples with dimensions 100x100x thickness (mm^3) were tested under laboratory conditions (t=20°C, φ=65 %) with an accuracy of ±0.001W.m^{-1}.K^{-1}.

RESULTS AND DISCUSSION

Analysis of properties of straw, wood and mixed pulp

Refining of straw pulp was performed on refiner Jylhä 0 using blades KU-25 with a 14° cutting angle for the above mentioned conditions. Blades KF-30 with a 52° cutting angle were used as first, however a collection of longer straw particles occurred at the inlet to the refiner. It caused a filtration of particles and only small particles were released for the further refining. A milling curve is shown in Fig. 1.

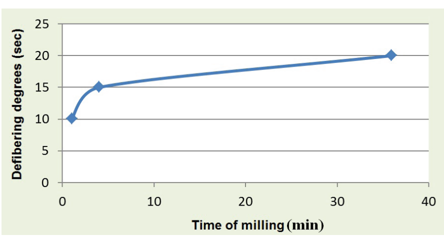

Fig. 1: Milling curve-dependence of DD on time of the straw pulp milling using blade KF 3.

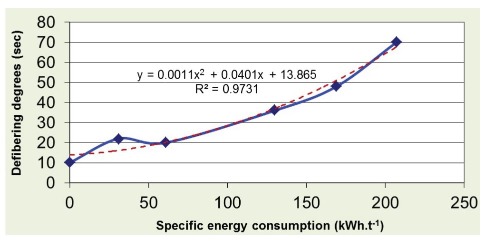

Fig. 2: Specific energy consumption for the straw pulp milling using blade KU 25.

This defect was removed using the universal blades KU-25 with a 14° cutting angle. Curve of the refining expressed according to the milling energy consumed is shown in Fig. 2.

The refining of the straw was carried out in water suspension with 3.0 % of the dry matter which circulated at 90°C. DD were checked while continuously. The refining was stopped after a value DD 70 achieved. The total time of the refining was 27 min. The specific energy consumption growths with DD increase. At DD70 reaches a value of 200 kWh.t^{-1}.

A percentage of particles (chips) is gradually reduced according to increased time of the refining until 10.15 % (Tab.1). The representation of other fractions of fibers was also changed. The percentage of long fibers (Mesh 40) positively increased with a growing time of the refining and growing of DD from 26.61 % for the 4 min refining to 48.51 % for the 27 min refining (DD70). The representation of short fibers (Mesh 120) does not change significantly. Decrease from 14.6 % for 4 min to 13.96 % for 27 min is only slight. Only the 10.26 % representation of short fibers is achieved under laboratory milling conditions. The high proportion of short fibers 19.66 % occurs under the laboratory preparation of wood pulp. Even flatter the representation occurs for fine fibers (Mesh 240), the value of 5.63 % for the 4 min refining rises to 8.53 % at 27 min. It achieves only 6.39 % in laboratory conditions.

Tab. 1: Distribution of straw pulp prepared by a straw pilot refining in VUPC.

Sample		**Milling 4 min**	**Milling 8 min**	**Milling 12 min**	**Milling 22 min**	**Milling 27 min**	**Laboratory milling of straw (Lübke et al. 2014)**	**Refined wood pulp Smrečina**
DD (sec)		14	25	39	58	70	68	37
Brecht – Holl (%)	Chips	48.35	37.94	32.59	20.01	10.15	7.510	7.58
	Mesh 40	26.61	30.22	33.96	40.75	48.51	46.44	52.79
	Mesh120	14.60	14.19	10.77	12.52	13.96	10.26	19.66
	Mesh240	5.63	7.57	7.10	8.77	8.53	6.39	9.02
	above 240 Mesh	4.81	10.07	15.56	17.94	18.84	29.40	10.95
WRV (%)						132.3		94.8
Dewatering (sec) (concentration 6 g/ 1000 ml H_2O)	dewatering amount 800 ml	26.0	48.4	65.2	87.6	95.6	166.2	27.5

The representation of the residual fine fibers (above Mesh 240) is increased from 4.81 to 18.84 % in the dependence of time of the refining. The high value of 29.40 % was achieved under laboratory milling conditions (Lübke et al. 2014). Wood fiber contains 10.95 % of such fibers. It's obvious that the straw milling gradually reduces the amount of particles and also positively increases the representation of long fibers (Fig. 3). The high presence of residual fine fibers was shown to be negative for physic-mechanical properties and also in view of the mat dewatering during the preparation of boards.

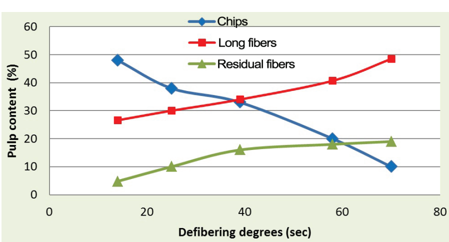

Fig. 3: Distribution of straw pulp according to Brecht-Holl under semi-production conditions.

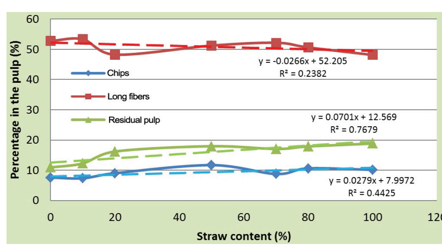

Fig. 4: Distribution of mixed pulp with the different wood/straw ratio according to Brecht-Holl.

In terms of physical-mechanical properties the overall presence of fine and residual fine fibers until 15 to 20 % is positive due to filling the spaces between long fibers, connecting each other and thus increases the contact surface of the fibers. On the other hand, a high percentage of their representation increases share of glue captured on the surface. A dewatering of refined straw compared to wood fiber is significantly worse. This fact is probably due to specific ends of straw fibers and the increased amount of residual fine fibers also. Dewatering time of straw pulp is already after 4 min at the level of refined wood fiber. The drainage of 800 ml of water is done after 95.6 sec for the 27 min refining straw, whereas the drainage time of wood fiber is 27.51 sec. Laboratory refined straw has the drainage time (166.2 sec) significantly worse compared to the pilot plant milling straw (Tab. 1). The distribution of the fibers is advantageous in wood fibers particularly in terms of the lower representation of chips and lower residual values of fine fibers.

Analysis of mixed pulp

Straw pulp prepared at pilot plants was added to the wood fibers produced in Smrečina Hofatex, a.s. The appropriate proportion of wood and straw pulp was mixed in the water suspension with a dry matter 1.5 %. The sample was taken for a fiber analysis. Subsequently, the mixed pulp was used for IFB. The distribution of fibers reached at a different mixing ratio is shown in Tab. 2.

The increased contribution of straw pulp increases the proportion of particles in the pulp, whereas the representation of the long fibers ranges between 48-53 %. Short-fiber content decreases due to the higher straw content; its impact on the properties of IFB is neutral or negative. The representation of fine fibers (Mesh 240) does not change significantly. The residual fine fibers (Mesh 240) increase due the straw growth from 10.95 to 18.80 %, which represents the 72 % increase. This fact negatively affects a dewatering of the mat in the manufacture and a swelling of finished IFB also.

Tab. 2: Distribution of the pulp used for the preparation of IFB with the different wood/straw ratio.

Sample		100 % wood	10 % straw + 90% wood	20 % straw + 80% wood	50 % straw + 50% wood	70 % straw + 30% wood	80 % straw + 20% wood	100 % straw
DD (sec)		37	39	42	51	58	66	70
Brecht – Holl (%)	Chips	7.58	7.33	9.01	11.71	8.77	10.62	10.15
	Mesh 40	52.79	53.38	48.25	51.25	52.17	50.64	48.51
	Mesh120	19.66	18.82	19.85	14.46	14.30	12.46	13.96
	Mesh240	9.02	8.22	6.67	4.62	7.70	8.39	8.53
	above Mesh 240	10.95	12.25	16.20	17.95	17.05	17.87	18.80
WRV (%)		94.80	103.20	110.20	125.20	130.50	132.20	132.30
Dewatering (sec) (concentration 6 g/ 1000 ml H_2O)	dewatering amount 800 ml	23.27	29.68	36.91	57.44	69.16	79.30	95.60

This indicates that the percentage of fractions as chips and long fibers does not substantially change with a straw content growth (Fig. 4). The dewatering of mixed fibers deteriorates due the increased concentration of straw fibers, which is consistent with previous determinations. The increase from 23.27 to 95.6 presents 310 %. This fact will have to be solved with an increased operational performance of drainage facilities resp. by adding of drainage agents.

The percentage of retained water in a mixed fiber increases with the growth of the representation of straw fibers in the mixture, which is also consistent with previous determinations. The increase of WRV from 94.8 to 132.3 % presents 40 %. The reason for this fact needs to be connected to anatomical differences between wood and straw (Lübke et al. 2014).

Analysis of IFB prepared from the wood and straw pulp under semi-production conditions

A density of IFB prepared with different wood/straw ratio ranges between 0.257-0.278 g.cm^{-3}. The measured properties were converted due to a better comparison to the density of 0.250 g.cm^{-3}. The density achieved in comparison to the densities at the common milling of the mixed pulp is significantly lower, corresponding to a substantially lower residual fine fibber content (from 24.8 to 18.8 %) and also a lower value of DD (from 130 to 70) (Ihnát et al. 2014). It means that the separately milling of straw and wood is needed for the require density achieve.

Manufacturers of insulation boards declare a minimum flexural strength 0.8 MPa at 0.250 g.m^{-3}. Achieved flexural strengths exceed the required minimum two-three times (Tab. 3). A variance of strengths is just 0.4 MPa although the ratio varied between 0 – 100 %. Values do not deteriorate; they remain on the same level with a moderate growth tendency (Fig. 5).

Tab. 3: Mechanical properties of IFB prepared from the straw and wood pulp recalculated for density of 0.250 g.cm^{-3}.

Straw content (%)	Density (g.cm^{-3})	Flexural strength (MPa)	Internal bond strength (kPa)	Flexural strength recalculated (MPa)	Internal bond strength recalculated (kPa)
0	0.263	1.55	39.5	1.47	37.54
10	0.278	1.86	46.5	1.67	41.82
20	0.270	1.75	44.5	1.62	41.22
30	0.269	1.68	41.5	1.56	38.57
40	0.266	1.78	42.5	1.67	39.94
50	0.262	1.86	46.0	1.77	43.89
70	0.268	1.93	47.0	1.80	43.84
80	0.257	1.86	47.5	1.81	46.21
100	0.258	1.85	46.0	1.80	44.74

Internal bond strength achieves 43.5 kPa in the average with the 8 kPa variance range. Minimum internal bond strength declared by the manufacturers of insulating fibreboards with the density of 0.250 g.cm^{-3} is 50 kPa. The values determined for samples prepared with the different representation of straw pulp are slightly lower. It's due to wood pulp produced with the low value of defibering degrees (DD = 37 sec.). The boards prepared from pure wood pulp have the lower value than the others with the addition of straw.

The progress of the internal bond strength based on the content of straw (Fig. 5) has the same course as in the case of flexural strength. A growth of the representation of straw fibers causes the minimal growing of the internal bond strength. The swelling of insulation boards with different content of straw pulp after converting to the density of 0.250 g.cm^{-3} is in the range 2.66 - 3.12 %. (Tab. 4). A maximum swelling declared by the producer for this density is about 5 %. It follows that all the alternatives meet the criteria declared by the manufacturer of IFB. The growth of straw pulp content does not increase the swelling. The tendency is rather slightly decreased (Fig. 6).

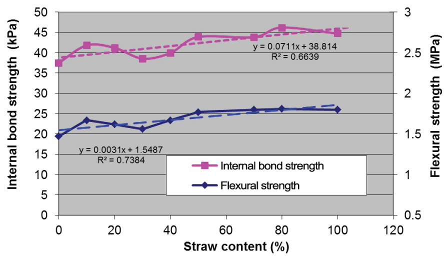

Fig. 5: Dependence of the mechanical properties of the prepared insulating boards on the content of straw pulp converted to the density of 0.250 g.cm^{-3}.

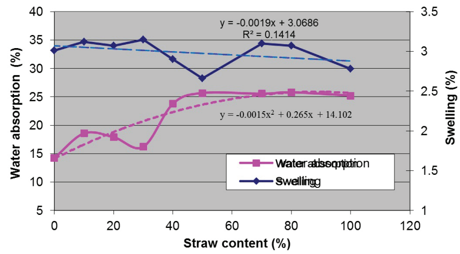

Fig. 6: Dependence of the physical properties of the prepared IFB on the straw pulp content converted to the density of 0.250 g.cm^{-3}.

Tab. 4: Physical properties of prepared insulating plates containing straw and wood pulp converted to the density of 0.250 g.cm^{-3}

Straw content (%)	Density (g.cm^{-3})	Swelling after 2 hours (%)	Water absorption after 2 hours (%)	Swelling after 2 hours recalculated (%)	Water absorption after 2 hours recalculated (%)
0	0.263	2.86	13.54	3.01	14.24
10	0.278	2.81	16.70	3.12	18.57
20	0.270	2.84	16.57	3.07	17.90
30	0.269	2.93	15.05	3.15	16.19
40	0.266	2.72	22.35	2.90	23.78
50	0.262	2.54	24.50	2.66	25.68
70	0.268	2.90	23.84	3.10	25.55
80	0.257	2.99	25.10	3.07	25.80
100	0.258	2.69	24.55	2.78	25.23

The water absorption depending on the content of straw fibers at concentrations up to 50 % sharply increases. The further increasing the fiber content but does not impair the water absorption. The cause of the increasing of water absorption is the same as an increased amount of water retention by straw fiber. As mentioned above, the reason is the anatomical structure of a stubble. As with the laboratory prepared straw fiber insulation boards (SIFB) (Lübke et al. 2014) also in this case the higher absorption does not cause the increase of values of the swelling or degradation of the mechanical properties.

A coefficient of thermal conductivity (λ), as a characteristic material value of insulation boards, important for the application of materials in construction, was established for prepared IFB. The values of the coefficient of thermal conductivity (Tab. 5) decrease with increase of the content of straw pulp gradually from 0.056 to 0.045 Wm^{-1}K^{-1} after a recalculation for the density of 0.250 g.cm^{-3}.

Tab. 5: Coefficient of thermal conductivity of SIFB in the dependence on the straw content.

Straw content (%)	Density ($g.cm^{-3}$)	λ ($Wm^{-1}K^{-1}$)	λ ($Wm^{-1}K^{-1}$) recalculated to 250 $g.cm^{-3}$
0	0.257	0.058	0.056
10	0.267	0.060	0.056
20	0.268	0.058	0.054
30	0.263	0.058	0.055
40	0.252	0.054	0.053
50	0.252	0.052	0.051
70	0.255	0.051	0.049
80	0.259	0.050	0.048
100	0.276	0.050	0.045

The graph of the dependence has a falling progress (Fig. 7). The overall improvement in the coefficient of thermal conductivity is 19.6 %. This fact is caused, similar to the increase in the absorption of the insulating boards, by larger diameters of straw vessels compared to wood ones, thus increasing the internal volume of fibers.

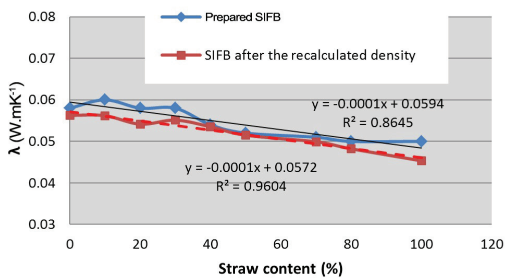

Fig. 7: Dependence of the coefficient of thermal conductivity of SIFB depending on the content of straw pulp.

CONCLUSIONS

Conclusions from the preparation and characterization of SIFB under pilot conditions

It can be concluded that:

- The refining of a straw under semi-production causes the obtaining of 18.84 % residual fine fibers, which gives conditions to achieve the desired density of SIFB which is 0.250 $g.cm^{-3}$. As compared with the common grinding of wood and straw fibers, where 24.8 % of residual fine fibers were achieved with a board density of 0.411 $g.cm^{-3}$. It follows that, for the desired 0.250 $g.cm^{-3}$ density of insulation panels should be straw and wood milled separately.
- The dewatering time of straw pulp is 310 % higher than of wood pulp.
- The amount of water held in straw fibers is 40 % higher than in wood fibers causing higher water absorption of SIFB.
- Conclusions of the fibre analysis that boards prepared using of straw pulp have desired density of 0.250 $g.cm^{-3}$ when DD= 70 sec were confirmed.
- SIFB with a 10 – 80 % straw pulp content prepared by separate grinding have the flexural

strength, internal bond strength and swelling at the same level IFB (only wood fibers) and meet the requirements of the manufacturers of IFB.
- The increased water absorption of insulation boards with a higher content of straw pulp is natural and it is caused by the different anatomical composition of the stalk and has not negative effects on other properties.
- The increased straw content improves the coefficient of thermal conductivity of SIFB with the density of 0.250 g.cm^{-3} to about 19.6 %.

ACKNOWLEDGMENTS

The achieved research results originated during the solution of the applied research project titled „Conversion of Fluting Production Technology in Smurfit Kappa Štúrovo". The project was supported by the Ministry of Education, Science, Research and Sports of Slovak Republic in frame of incentives provided for research and development from the national budget based on law No. 185/2009 C. about incentives for research and development. This work was supported by the Ministry of Education, Science, Research and Sport of the Slovak Republic under contract No. 1251/2009.

REFERENCES

1. Han, J.S., 1998: Fiber property comparison. 1998 TAPPI North American Nonwood. Fiber Symposium, February 17-18, Atlanta.
2. Felby, C., Thygesen, L.G., Sanadi, A., Barsberg, S., 2004: Native lignin for bonding of fiber boards—evaluation of bonding mechanisms in boards made from laccase-treated fibers of beech (*Fagus sylvatica* L.). Industrial Crops and Products 20(2): 181-189.
3. Hornsby, P.R., Hinrichsen, E., Tarverdi, K., 1997: Preparation and properties of polypropylene composites reinforced with wheat and flax straw fibres. Part 1: Fibre characterization. Journal of materials science 32(2): 443-449.
4. Ihnát, V., Borůvka, V., Lübke, H., 2015: Straw pulp as a secondary lignocellulosic raw material and its impact on properties of properties of insulating fiberboards. Part II. Preparation of insulating fiberboards with straw content. Wood Research 60(2): 235-246.
5. Lübke, H., Ihnát, V., Borůvka, V., 2014: Straw pulp as a secondary lignocellulosic raw material and its impact on properties of properties of insulating fiberboards. Part I. Characteristic of straw fibre from the perspective of the mass creation. Wood Research 59(5): 747-755.
6. Mo, X., Cheng, E., Wang, D., Sun, X.S., 2003: Physical properties of medium-density wheat straw particleboard using different adhesives. Industrial Crops and Products 18(1): 47-53.
7. Majumdar, P., Chanda, S., 2001: Chemical profile of some lignocellulosic crop residues. Indian J. Agric. Biochem. 14(1-2): 29-33.
8. Mohanty, A.K., Misra, M., Hinrichsen, G., 2000: Biofibres, biodegradable polymers and biocomposites. An overview. Macromolecular Materials and Engineering 276/277(1): 1-24.
9. Saheb, N.D., Jog, J.P., 1999: Natural fiber polymer composites: A review. Advances in Polymer Technology 18(4): 351-363.
10. STN EN 622-4, 2000: Fibreboards. Specifications. Part 4: Requirements for softboards.

11. STN EN 310, 1998: Wood-based panels. Determination of modulus of elasticity in bending and of bending strength.
12. STN EN 317, 1995: Particleboards and fibreboards. Determination of swelling in thickness after immersion in water.
13. STN EN 319, 1995: Particleboards and fibreboards. Determination of tensile strength perpendicular to the plane of the board.
14. STN 50 0289, 1984: Pulp testing. Determination of fractional composition of pulp.
15. Sukumaran, K., Satyanarayana, K.G., Pillai, S.G.K., Ravikumar, K.K., 2001: Structure, physical and mechanical properties of plant fibres of Kerala. Metals Materials and Processes 13(2-4): 121-136.
16. Wang, D., Sun, X.S., 2002: Low density particleboard from wheat straw and corn pith. Industrial Crops and Products 15(1): 43-50.
17. Yang, H.S., Kim, D.J., Kim, H.J., 2003: Rice straw–wood particle composite for sound absorbing wooden construction materials. Bioresource Technology 86(2): 117-121.
18. Youngquist, J.A., English, B.E., Scharmer, R.C., Chow, P., Shook, S.R., 1994: Literature review on use of nonwood plant fibers for building materials and panels. Madison, WI, Forest Products Laboratory, 146 pp.

Vladimír Ihnát*
Slovak Forest Products Research Institute
Lamačská 3
841 04 Bratislava
Slovak Republic
Phone: +421 2 59418 633
Corresponding author: ihnat@vupc.sk

Vlastimil Borůvka, Marian Babiak
Czech University of Life Sciences Prague
Faculty of Forestry and Wood Sciences
Department of Wood Processing
Kamýcká 129
165 21 Prague 6
Czech Republic

Henrich Lübke, Jiří Schwartz
Slovak Pulp and Paper Research Institute, Inc.
Lamačská 3
841 04 Bratislava
Slovak Republic