ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 57(2): 89−95, 2015
Zvolen, Technická univerzita vo Zvolene
DOI: 10.17423/afx.2015.57.2.09

BENDING STIFFNESS FOR HANDSHEETS MADE OF A BLEND OF SECONDARY FIBRES AND CHEMI-MECHANICAL PULP FROM RAPESEED STRAW

František Potůček – Martina Říhová

ABSTRACT

The aim of this study was to investigate bending stiffness characteristics for handsheets made of a blend of secondary fibres and chemi-mechanical pulp from rapeseed straw, in mass ratio of 3 : 1, and 1 : 1, with a basis weight of around 520 $g \cdot m^{-2}$. To manufacture chemi-mechanical pulp, three cold processes, namely neutral sulphite, alkaline sulphite, and caustic soda, were applied under laboratory conditions. The chemi-mechanical pulping comprises four main operations, viz. chipping, grinding, leaching, and beating to 43–46 °SR (Schopper-Riegler degree). The chemi-mechanical pulp was characterized by its degree of polymerization which was measured in the range of 75 to 110 with respect to relatively great amount of low molecular substances presented in pulps prepared by cold pulping process. The results obtained showed that the addition of chemi-mechanical pulp to secondary fibres led to a decrease in the bending stiffness, bending modulus of elasticity in the region of reversible deformation, as well as in the maximum curvature in the region of reversible deformation, and in critical curvature in the region of plastic deformation. However, the bending modulus of elasticity and maximum curvature was found to be comparable with those measured for moulded fibre products in our previous studies.

Keywords: rapeseed straw; cold pulping process; secondary fibres; chemi-mechanical pulp; bending stiffness.

INTRODUCTION

Nowadays, wood is the dominant resource for pulp and paper production which is increased continuously. However, since wood is not available in sufficient quantities in many countries, alternative new non-wood raw materials such as annual plants and agricultural waste are searched for exploitation as the potential substitution of wood (GURUNG, POTŮČEK 2013).

Rapeseed is widely cultivated throughout the world and considered as the third most oilseed crop after soybean and palm. Its seeds are basically used for production of edible oil and further utilized in biodiesel production (POTŮČEK, MILICHOVSKÝ 2011). The influence of European Union's legislation to reach the consumption of biofuel to 10 % of the total at minimum by 2020 has led the production of rapeseed to be doubled in last 10 years (GONZALEZ *et al.* 2013). After the harvest of grains, the straw is left in the field as residue and let to be composted or burnt otherwise. Depending upon the irrigation facilities, the total amount of biomass produced varies from 5 to 10 $t \cdot h^{-1}$ and approximately 20 % of the rapeseed biomass in the field possesses stem portion (SAMARIHA *et al.* 2011). In the Czech Republic, the planted area achieved over 400 thousand hectares. After rapeseed seed collection, the total amount of straw produced per unit area varies from 2.8 to 4.5 $t \cdot ha^{-1}$ (PETŘÍKOVÁ 1999). However, these agricultural wastes can be utilized as fibrous raw material for pulp and paper production. Fibres from rapeseed straw used as secondary fibres bring better mechanical properties than recycled papers (GONZALEZ *et al.* 2013). Moreover, YOUSEFI (2009) has found promising results in utilizing the rapeseed straw in medium density fibreboard.

The objective of the present study was to prepare chemi-mechanical pulp from rapeseed straw by cold pulping processes at a room temperature under laboratory conditions. For blends of secondary fibres with chemi-mechanical pulp, the bending stiffness, bending modulus of elasticity, maximum curvature in the region of elastic deformation, and critical curvature in the region of plastic deformation were measured using the three-point loading method. The results obtained in this work were compared with those determined for moulded fibre specimens made from secondary fibres only.

EXPERIMENTAL PART

Rapeseed straw (*Brassica napus* L. convar. *napus*, line genotype Labrador) collected from the field in Polabian lowlands near city of Pardubice (Czech Republic) was used as a raw material to chemi-mechanical pulping experiments. The stalks and valves of silique were cut manually into small chips having a length of about 20 mm. After drying at 60 °C for 5 hours, the chips of stalks and of silique valves were ground for 20–25 s using a laboratory vibrating mill containing a roller and collar in the milling space. Fine mass of accepts retained on +50 mesh size was used for leaching. The samples of fine material to be leached were blends of the stalks and silique valves in the mass ratio of 2 : 1. Three various cold pulping processes, viz. neutral sulphite, alkaline sulphite and caustic soda, were applied at an active alkali charge of 16 mass % of Na_2O on oven dry straw. For the liquor-to-straw ratio of 15 : 1, the leaching was performed for 18 hours at a temperature of 21–23 °C. For comparison, the leaching of blend of stalks and silique valves into tap water was carried out as well.

After four-stage batch washing, the wet pulp was beaten to 43–46 °SR using a laboratory conical beater. The beating degree was measured by Schopper-Riegler method according to ISO 5267-1 Standard. The suspension of beaten chemi-mechanical pulp was mixed with the secondary fibres obtained by slushing of egg trays in water in the mass ratio of 1 : 3, and 1 : 1. Egg trays from Huhtamaki Czech Republic, a. s., were manufactured from a blend of waste papers, namely newspapers, magazine paper, waste corrugated board and non-sorted waste papers. The secondary fibres and chemi-mechanical pulp, as well as their blends were used to prepare pulp handsheets having basis weight of around 520 $g \cdot m^{-2}$ on a Rapid-Köthen sheet forming machine.

To determine the stiffness properties, the stripes, 15 mm in width and 90 mm in length, were cut from the pulp handsheets. Using a TIRA test 26005 device, the bending stiffness was determined by the three-point loading method when the distance between supports was kept at 50 mm (Fig. 1). Strength characteristics were measured under a constant room temperature of (23 ± 1) °C and relative humidity of (50 ± 2) %. All the strength measurements were performed at least on 20 replicates per each tested sample.

The bending stiffness, S, is defined as

$$S = \frac{F l^3}{48 y} \tag{1}$$

where F/y corresponds to the slope in the region of elastic deformation, at low acting forces, when the dependence of the acting force on the deflection is straight (Fig. 2), and l is the distance between supports.

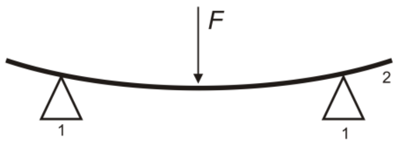

Fig. 1 The 3-point loading method.
1 supports, 2 specimen of pulp sheet.

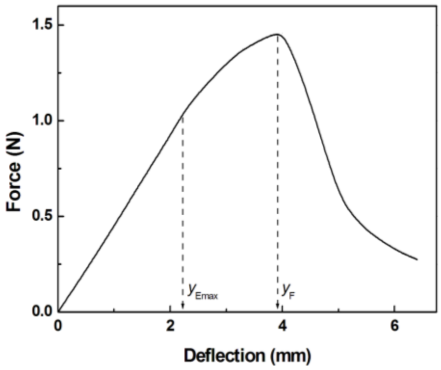

Fig. 2 Typical dependence between specimen deflection and acting force measured for chemi-mechanical pulp handsheet.

The bending modulus of elasticity in the region of reversible deformation, E, is given by the following equation

$$E = \frac{F l^3}{4 y b h^3} \tag{2}$$

where b is the specimen width, h is the specimen thickness, and a meaning of other symbols is the same as in equation (1). Thus, equation (2) may be written as $E = 12\, S / (b \cdot h^3)$.

The maximum curvature in the region of reversible deformation, C_E, is defined as

$$C_E = \frac{12 y_{E_{max}}}{l^2} \tag{3}$$

where y_{Emax} is the maximum deflection of specimen measured in the region of the reversible deformation.

The critical curvature, C_F, is given by the following equation

$$C_F = \frac{12 y_F}{l^2} \tag{4}$$

where y_F is the deflection of the specimen attained in the region of non-reversible deformation.

To characterize chemi-mechanical pulps, the average degree of polymerization was determined by a viscosity test using FeTNa solution, *i. e.*, iron (III) sodium tartrate complex as a solvent for chemi-mechanical pulp according to ISO 5351/2-1981.

RESULTS AND DISCUSSION

To characterise chemi-mechanical pulps, the average degree of polymerization of 77, 100, 108, and 112 was determined for mechanical pulp, neutral sulphite, alkaline sulphite, and caustic soda pulps, respectively. The low values of degree of polymerization can be attributed to the presence of low molecular substances, mainly hemicelluloses, in chemi-mechanical pulps. Moreover, the rapeseed contains short fibres having the average length around 1 mm. In our previous paper (POTŮČEK *et al.* 2014), the average weighted length was found to be 0.84 mm for soda pulp cooked from rapeseed straw (genotype Labrador).

For comparison ENAYATI *et al*. (2009) and MOUSAVI *et al*. (2013) reported the fibre length of 1.17 mm for pulp from canola stalks and of 1.03 mm for pulp from rapeseed straw, respectively.

The bending stiffness is a property of paper and board which expresses its rigidity or resistance to bending. A typical dependence between specimen deflection (y), and acting force (F) for chemi-mechanical pulp made from rapeseed straw using cold caustic soda process is illustrated in Fig. 2.

Bending stiffness (S) as a function of mass fraction of chemi-mechanical pulp in the blend of fibres is illustrated in Fig. 3. The results show that the bending stiffness decreases with the addition of chemi-mechanical pulp into secondary fibres. In comparison with secondary fibres, the bending stiffness measured for a blend of secondary fibres and CMP in the mass ratio of 1 : 1 was lower by nearly 30 %. For a blend with 25 % of CMP, the bending stiffness of pulp containing CMP after cold caustic soda and of mechanical pulp is greater than that of pulp containing CMP after cold neutral and alkaline sulphite processes.

However, it is known that the bending stiffness increases strongly with increasing thickness of test specimen, theoretically with the third power of pulp sheet thickness, *e. g*., POTŮČEK *et al*. (2007) found that $S \approx h^{2.81}$ and $S \approx h^{3.11}$ for moulded fibre products, depending on manufacturing conditions. Hence, the bending stiffness results depend not only on composition of stock used for handsheets, but also on their thickness. While for secondary fibres the thickness of handsheet was only 0.88 mm, the addition of 25 % and of 50 % of CMP to the secondary fibres stock brought an increase in handsheet thickness of 0.96 to 1.16 mm, and of 1.00 to 1.43 mm, respectively. It should be noted that, for both charge of CMP, the thickness of handsheet increased in the following order, viz. of caustic soda pulp < alkaline sulphite pulp < neutral sulphite pulp < mechanical pulp made after water leaching processes. Furthermore, it is worth mentioning that pulp handsheets made from blends of secondary fibres and chemi-mechanical pulp had a much higher bulk in comparison with handsheets made form secondary fibres only.

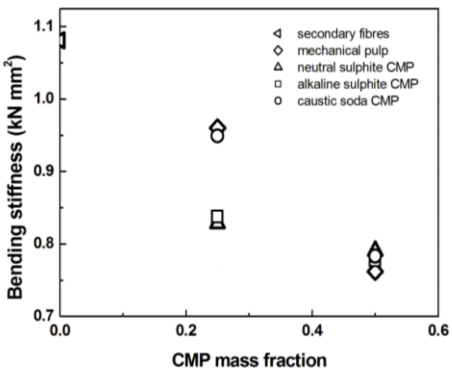

Fig. 3 Influence of mass fraction of CMP on the bending stiffness.

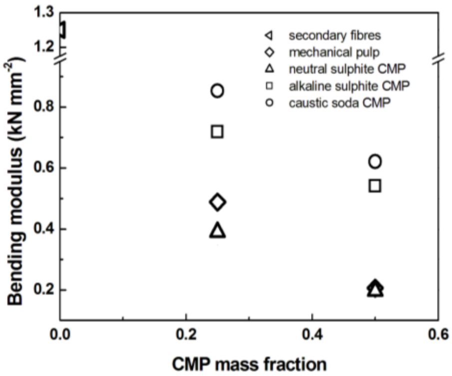

Fig. 4 Influence of mass fraction of CMP on the bending modulus of elasticity in the region of reversible deformation.

Our previous results (POTŮČEK *et al*. 2008) showed that the bending modulus of elasticity in the region of reversible deformation has a decreasing trend with increasing thickness of groundwood specimens. The influence of the presence of CMP in a blend with secondary fibres on the bending modulus of elasticity (E) is shown in Fig. 4. It is evident that the bending modulus of elasticity decreases with increasing the mass fraction of CMP and MP. The greatest values of the bending modulus were measured for a blend of secondary fibres with caustic soda pulp. On the contrary, the lowest values of the bending modulus were achieved for neutral sulphite pulp in a blend with secondary fibres at both levels of CMP addition.

The maximum curvature in the region of reversible deformation (C_E) is plotted against the mass fraction of chemi-mechanical pulp in Fig. 5. Comparing with the secondary fibres, the lower values of the maximum curvature in the region of elastic deformation were measured for pulp handsheets prepared from a blend of secondary fibres with addition of CMP or MP. The pulp handsheets prepared from a blend of secondary fibres with addition of CMP or MP were less elastic in comparison with sheets from secondary fibres only. However, the influence of CMP addition is ambiguous. Increasing increment of CMP led to an increase in the maximum curvature for MP and CMP made by cold caustic soda process. On the contrary, the maximum curvature decreased with increasing amount of neutral sulphite and alkaline sulphite CMP in a blend with secondary fibres.

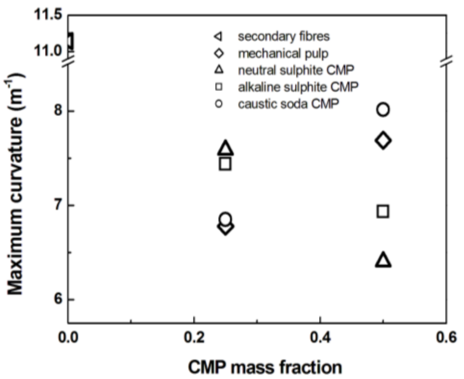

Fig. 5 Maximum curvature in the region of reversible deformation as a function of mass fraction of CMP.

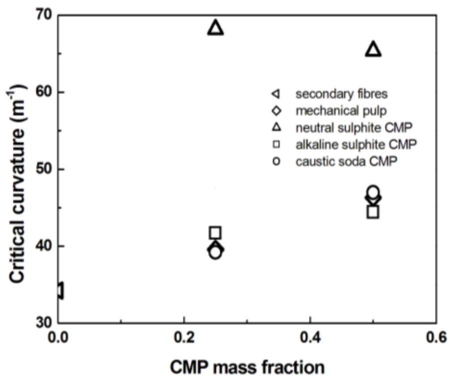

Fig. 6 Curvature for tensile crack as a function of mass fraction of CMP.

The influence of CMP addition on the critical curvature (C_F), for tensile crack is illustrated in Fig. 6. Tensile crack occurs in the region of irreversible or plastic deformation and is evident in the convex side of specimen below the neutral plane.

For MP, alkaline sulphite and caustic soda CMP, the quantity of the critical curvature was found to increase with their increment in secondary fibres. However, the greatest values of the critical curvature were measured for neutral sulphite CMP addition in secondary fibres even if the critical curvature slightly decreases with increasing amount of CMP. In spite of this fact, the addition of MP and CMP had a positive impact on the critical curvature of pulp handsheets which were less fragile in comparison with that of handsheets made from secondary fibres only.

Table 1 summarises the values of the bending modulus of elasticity and of maximum curvature in the region of elastic deformation obtained in this work. For comparison, the bending modulus and maximum curvature measured for moulded fibre specimens in the previous paper (POTŮČEK *et al*. 2007) are given in Table 1. Similarly as the bending modulus of elasticity, the maximum curvature in the region of reversible deformation revealed a slightly decreasing trend with increasing the thickness of specimens made from moulded fibre products when the thickness ranged from 1 to 2 mm. It should be noted that the tested specimens of moulded fibre products with basis weight of 360 to 620 $g \cdot m^{-2}$ were shaped through vacuum suction using special forms. In spite of these facts, the bending modulus of pulp handsheets measured for blends of secondary fibres and MP or CMP is comparable to that determined for moulded fibre specimens having the thickness of around 1 mm. On the other hand, the maximum curvature in the region of elastic deformation achieved for blends of secondary fibres and MP or CMP is comparable to that for moulded fibre specimens when the thickness of specimens approached 2 mm.

Tab. 1 Comparison of bending modulus of elasticity and maximum curvature in the region of elastic deformation measured for various blends of secondary fibres and CMP or MP and for samples of moulded fibre products (POTŮČEK *et al*. 2007).

Handsheet	Thickness mm	95% confidence limits of bending modulus, $kN \cdot mm^{-2}$	95% confidence limits of maximum curvature, m^{-1}
100% secondary fibres	0.88	1.20–1.29	10.5–11.8
		Mechanical pulp	
75% SF + 25% MP	1.16	0.461–0.516	5.70–7.22
50% SF + 50% MP	1.44	0.186–0.225	6.85–8.54
		Neutral sulphite pulp	
75% SF + 25% CMP	0.91	0.335–0.424	6.17–9.03
50% SF + 50% CMP	1.47	0.188–0.207	5.85–6.97
		Alkaline sulphite pulp	
75% SF + 25% CMP	0.98	0.684–0.753	6.59–8.29
50% SF + 50% CMP	1.05	0.518–0.564	6.33–7.54
		Caustic soda pulp	
75% SF + 25% CMP	0.96	0.809–0.896	6.42–7.28
50% SF + 50% CMP	1.00	0.570–0.672	6.65–9.38
Moulded fibre products	0.96 – 1.09	0.184–0.559	10.6–14.6
	1.85 – 1.97	1.52–2.02	5.25–8.22

CONCLUSIONS

The preliminary results obtained in the scope of our study proved that the addition of chemi-mechanical pulp prepared by the cold pulping processes, namely neutral sulphite, alkaline sulphite, and caustic soda, to secondary fibres led to a decrease in bending stiffness properties. Nevertheless, the results showed that the bending modulus of elasticity, as well as the maximum curvature in the region of elastic deformation are comparable to those measured for moulded fibre specimens in the previous paper. With respect to current knowledge of chemi-mechanical pulping of rapeseed straw, further studies should be developed to confirm the suitability of rapeseed as a future non-wood fibre source.

SYMBOLS

b	specimen width, mm
C_E	maximum curvature in the region of elastic deformation, m^{-1}
C_F	critical curvature in the region of plastic deformation, m^{-1}
E	bending modulus in the region of elastic deformation, $N \cdot mm^{-2}$
F	force, N
h	thickness of specimen, mm
l	distance between two support points, mm
S	bending stiffness, $N \cdot mm^2$
y	deflection, mm
y_{Emax}	maximum deflection in the region of reversible deformation, mm
y_F	deflection attained in the region of non-reversible deformation where tensile crack occurs, mm

Abbreviations

CMP chemi-mechanical pulp

MP mechanical pulp
SF secondary fibres

REFERENCES

ENAYATI, A. A., HAMZEH, Y., MIRSHOKRAIE, S. A., MOLAII, M. 2009. Papermaking potential of canola stalks. In BioResources, 2009, 4(1): 245–256.
GONZALEZ, I., ALCALA, M., ARBAT, G., VILASECA, F., MUTJE, P. 2013. Suitability of rapeseed chemothermomechanical pulp as raw material in papermaking. In BioResources, 2013, 8(2): 1697–1708.
GURUNG, B., POTŮČEK, F. 2013. Utilization of non-woody plants for pulp production. In Papír a celulóza, 2013, 68(5): 147–151.
ISO 5267-1: 2012. Pulps – Determination of drainability – Part 1: Schopper-Riegler method.
ISO 5351/2: 1981. Cellulose in dilute solutions – Determination of limiting viscosity number – Part 2: Method in iron (III) sodium tartrate complex ($EWNN_{mod\ NaCl}$) solution.
MOUSAVI, S. M. M., HOSSEINI, S. Z., RESALATI, H., MAHDAVI, S., GARMAROODY, E. R. 2013. Papermaking potential of rapeseed straw, a new agricultural-based fiber source. In Journal of Cleaner Production, 2013, 52, 420–424.
PETŘÍKOVÁ, V. 1999. In Rostliny pro energetické účely (Plants for energy purposes). Praha: Česká energetická agentura, 1999. 34 pp.
POTŮČEK, F., ČEŠEK, B., DOMIN, P., MILICHOVSKÝ, M. 2007. Stiffness of moulded fibre products. In Cellulose Chemistry and Technology, 2007, 41(4–6): 277–281.
POTŮČEK, F., ČEŠEK, B., MILICHOVSKÝ, M. 2008. Bending stiffness of groundwood sheets with and without sugar beet pulp addition. In Cellulose Chemistry and Technology, 2008, 42(7–8): 413–419.
POTŮČEK, F., GURUNG, B., HÁJKOVÁ, K. 2014. Soda pulping of rapeseed straw. In Cellulose Chemistry and Technology, 2014, 48(7–8): 683–691.
POTŮČEK, F., MILICHOVSKÝ, M. 2011. Rapeseed straw as a possible source of non-wood fiber materials. In Cellulose Chemistry and Technology, 2011, 45(1–2): 23–28.
SAMARIHA, A., KASMANI, J. E., KIAEI, M., SHURMASTI, D. K. 2011. Chemi-mechanical pulping (CMP) of rapeseed residues. In World Applied Sciences Journal, 2011, 13(5): 1000–1004.
YOUSEFI, H. 2009. Canola straw as a bio-waste resource for medium density fiberboard (MDF) manufacture. In Waste Management, 2009, 29(10): 2644–2648.

Acknowledgements

This work was supported by the Internal Grant Agency of University of Pardubice under the research project SGFChT04/2014.

Authors´ address:

Prof. Ing. František Potůček, CSc.
Ing. Martina Říhová
University of Pardubice
Faculty of Chemical Technology
Institute of Chemistry and Technology of Macromolecular Materials
Studentská 95
532 10 Pardubice
Czech Republic
frantisek.potucek@upce.cz
st27081@student.upce.cz