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STRENGTH CHARACTERISTICS OF CHEMI-MECHANICAL PULP FROM RAPESEED STRAW

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ABSTRACT

The objective of this work was to determine the potential application of rapeseed straw in the chemi-mechanical pulping process. Stalks of rapeseed straw (species *Brassica napus* L. convar. *napus*) were used for the pulping process. The chemi-mechanical pulping comprises four main operations, viz. chipping, grinding, leaching, and beating.

For chemi-mechanical pulps, the influence of caustic soda charge applied in the leaching process upon the bending stiffness and bending modulus of elasticity in the region of reversible deformation was investigated by using a three-point loading method. The preliminary results revealed that the bending modulus of elasticity increases with increasing caustic soda charge from 0.22 to 1.11 $kN·mm^{-2}$ for both basis weights of the handsheets (approx. 260 $g·m^{-2}$ and 520 $g·m^{-2}$). Similarly, the bending stiffness of handsheets having lower basis weight slightly increases with increasing alkaline charge, whereas, for higher basis weight, the effect of alkaline charge on the bending stiffness is ambiguous. Of course, the tensile strength of chemi-mechanical pulps was much lower than that published for kraft pulp or waste paper.

The results obtained for rapeseed straw were compared with those measured for unbleached spruce groundwood and for moulded fibre products, which were published earlier. The bending stiffness and bending modulus of elasticity were much greater than those for moulded fibre products made from waste paper.

Besides the strength characteristics, the degree of polymerization and bonding properties of rapeseed straw pulp were investigated. Owing to the presence of low molecular substances, the degree of polymerization of chemi-mechanical pulp was found to be within the limits of 96 to 224, depending on caustic soda charge applied in the leaching process.

Keywords: chemi-mechanical pulping; rapeseed straw; bending stiffness; degree of polymerization.

INTRODUCTION

Nowadays, non-woody plants are receiving more attention in order to fulfil the shortage of wood fibres in pulp and paper industry due to its abundance and cost effectiveness (FATEHI *et al.* 2009, HOSSEINPOUR *et al.* 2010). Among various sources of non-wood fibres, straw has been utilised in huge quantity and contributes as the largest source of non-wood raw material for the paper industry (SUN *et al.* 2001, HOSSEINPOUR *et al.* 2010). Many pulping technologies of non-woody plants like kraft, kraft-AQ, soda, soda-AQ, organosolv, etc., have been investigated previously along with the characteristics of pulp obtained (DENIZ *et al.* 2004, ATES *et al.* 2008, RODRIGUEZ *et al.* 2008, FIŠEROVÁ *et al.* 2006, ZOMERS *et al.* 1995). However, chemi-mechanical pulping of non-woody plants and their corresponding paper properties has gained much less attention. The potential applications of such chemi-mechanical pulps from non-woody plants include the production of newsprint, fluting papers and liner boards (YOUSEFI 2009).

Rapeseed is the third most important oilseed crop after soybean and palm. Its applicability is not only limited to edible oil production but also used in biodiesel production. Furthermore, it can be extended in pulp and paper industry as a source of non-wood fibres (POTŮČEK, MILICHOVSKÝ 2011). Recently, the utilisation of rapeseed straw in medium density fibreboard has shown promising results (YOUSEFI 2009). Soda pulping (ENAYATI *et al.* 2009, POTŮČEK, MILICHOVSKÝ 2011), organic acid pulping (BARBASH *et al.* 2011) and neutral sulphite semichemical pulping (AHMADI *et al.* 2010) are available in the literature. Nevertheless, the studies available on chemi-mechanical pulping of rapeseed straw are rare.

Hence, the objective of this work is to prepare pulp from rapeseed straw by chemi-mechanical pulping and to investigate the influence of the varying alkaline dosages in the leaching process on the strength properties like bending stiffness, bending modulus of elasticity, and tensile index as well. Moreover, the degree of polymerization and bonding properties determined by rheosedimentation method for rapeseed straw pulp were investigated.

EXPERIMENTAL

Rapeseed straw (*Brassica napus* L. convar. *napus*, in our case linie genotype Ontario) from Bohemian-Moravian Highlands was used for forming chemi-mechanical pulp. The rapeseed straw consists of various materials like stalks, valves of silique, debris, leaves, etc. Fine mass of stalks with varying diameter was obtained separating the valves of silique, debris and leaves from rapeseed straw. Then, the stalks were cut manually by flower scissor into small pieces producing the chips having length of 20 mm approx. Using a laboratory vibrating mill containing a roller and collar in the milling space, the dry chips were ground for 25–30 s and screened with wire sieve to remove fines. The accepts retaining on +50 mesh size were leached into aqueous solution of caustic soda with different dosages of caustic soda, namely 3.65, 9.75, and 15.9 % of Na_2O on oven dry straw, for 20 h at a laboratory temperature (Table 1). The straw was also leached only into tap water for 40 hrs. In this case, the pulping process may be called as mechanical pulping. The straw after leaching was washed in three stages based on dilution followed by thickening.

Tab. 1 Leaching conditions and properties of chemi-mechanical pulp specimens.

Leaching			Pulp specimens		
Liquor-to-straw ratio	Time h	Na_2O-charge % on o.d. straw	Beating degree SR	Thickness mm	Basis weight $g \cdot m^{-2}$
102 : 1	40	0	58	0.99	260
102 : 1	40	0	58	1.87	519
47 : 1	20	3.65	50	0.90	266
47 : 1	20	3.65	50	1.79	554
44 : 1	20	9.75	55	0.64	245
44 : 1	20	9.75	55	1.19	508
82 : 1	20	15.9	51	0.60	263
82 : 1	20	15.9	51	1.08	521

Using a laboratory conical beater, the wet straw after leaching process was beaten from initial beating degree of 11 to 50–58 SR (Table 1). Beating degree was measured by Schopper-Riegler method according to ISO 5267-1 Standard. Both sorts of beaten pulps, chemi-mechanical and mechanical, were used to make handsheets on a Rapid-Köthen sheet forming machine. Handsheets of two different levels of basis weight (B. W., for short), approximately 260, and 520 g·m^{-2}, were prepared.

In order to determine stiffness properties, the stripes, 15 mm in width and 90 mm in length, having basis weight of about 260, and 520 g·m^{-2} were made from the handsheets obtained from chemi-mechanical pulp, as well as mechanical one. Then, the stripes were used to measure the bending stiffness on a TIRA test 26005 device using three-point loading method under a constant room temperature of 23 °C and relative humidity of 50 %. The distance between the supports was kept at 50 mm.

For strips, 150 mm in length, having basis weight of 75 to 87 g·m^{-2}, the tensile properties, namely the tensile index, breaking length and relative elongation were determined as well. All strength measurements were performed at least on 20 replicates per each tested sample.

The average degree of polymerization of rapeseed straw fibres was determined from the limiting viscosity number using a capillary viscometer. Viscosimetric measurements were performed in accordance with the T230 om-89 TAPPI Test Method, however, pulp fibres were dissolved in cadoxen, a solution of cadmium oxide in aqueous ethylene diamine.

RESULTS AND DISCUSSION

The bending stiffness is a property of paper and board which expresses its rigidity or resistance to bending. It is the product of bending modulus of elasticity and moment of inertia. Generally, for given material the bending stiffness depends strongly upon the thickness of test specimen and rises linearly with increasing moment of inertia, theoretically with the third power of thickness of paper sheet (POTŮČEK *et al.* 2008).

The bending stiffness, *S*, was evaluated from the following equation

$$S = \frac{F\,l^3}{48y} \qquad (1)$$

where *F* is acting force, *l* is distance between two support points, and *y* is deflection of tested specimen.

The results obtained showed that the bending stiffness is apparently higher for specimen with higher thickness. Figure 1 shows the dependence of bending stiffness on the caustic soda charge (expressed as % Na_2O on oven dry straw of rapeseed) used in the leaching process. For the specimens with lower basis weight (245–266 g·m^{-2}), it is evident that the bending stiffness increases slightly with increasing caustic soda charge. However, in the case of specimens with higher basis weight (508–554 g·m^{-2}), the effect of caustic soda charge is ambiguous.

The bending modulus of elasticity, *E*, is defined as

$$E = \frac{F\,l^3}{4y\,b\,h^3} \qquad (2)$$

where *b* is specimen width and *h* is specimen thickness. The other symbols have the same meaning as in equation (1).

The bending modulus of elasticity in the region of reversible deformation as a function of caustic soda charge is illustrated in Fig. 2. It is clear that the bending modulus of elasticity is not appreciably different for specimens having various basis weights, except for zero caustic soda charge when mechanical pulp was made. The bending modulus of elasticity obtained for chemi-mechanical pulps lie within the limits of 0.22 to 1.11 kN·mm^{-2} and is lower than that (0.9 to 1.9 kN·mm^{-2}) reported by POTŮČEK *et al.* (2008) for unbleached spruce groundwood having a thickness of 0.6 to 1.9 mm.

Furthermore, the stiffness results obtained for rapeseed straw pulps were compared with those published earlier for unbleached spruce groundwood and moulded fibre products. At almost constant thickness of the handsheets, the bending stiffness and bending modulus of elasticity in the region of reversible deformation measured for highest charge of caustic soda are comparable to those measured for unbleached spruce groundwood and are much greater in comparison with those obtained for moulded fibre products made from waste paper (Table 2). However, the bending stiffness and bending modulus of elasticity determined for mechanical pulp, when leaching into tap water was carried out, are somewhat lower than those published for moulded fibre products previously (POTŮČEK *et al.* 2007; POTŮČEK *et al.* 2008).

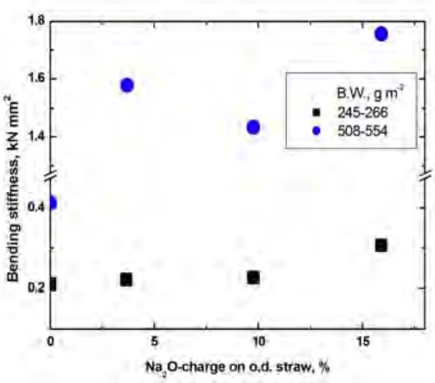

Fig. 1 Bending stiffness as a function of Na_2O-charge on oven dry straw.

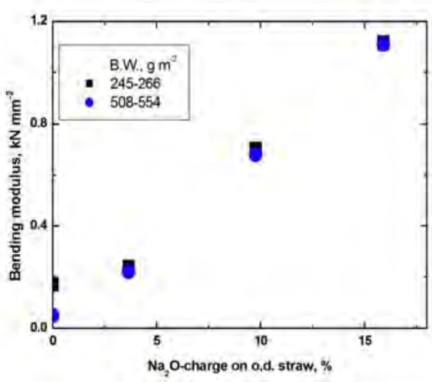

Fig. 2 Bending modulus of elasticity as a function of Na_2O-charge on oven dry straw.

Tab. 2 Comparison of stiffness properties measured for various materials

Material	Thickness mm	Bending stiffness kN·mm^{-2}	Bending modulus kN·mm^{-2}
Rapeseed straw pulp (0 % Na_2O)	0.99	0.220	0.180
Rapeseed straw pulp (15.9 % Na_2O)	1.08	1.756	1.109
Spruce groundwood[1]	1.006	1.624	1.274
Waste paper (moulded fibre products)[2]	1.01	0.343	0.265

[1] Potůček *et al.* 2008, [2] Potůček *et al.* 2007

The tensile strength belongs among important properties of papers with low basis weight used as wrapping papers. Nevertheless, it can be expected that chemi-mechanical pulps are not a material suitable for this purpose. For handsheets having basis weight within the interval from 75 to 87 g·m^{-2} and the thickness ranging of 0.25 to 0.37 mm, the tensile index increases with increasing charge of soda caustic (Fig. 3) but the values obtained were much lower than those reported previously by POTŮČEK *et al.* (2013) who measured 78.4 and 37.4 N m g^{-1} for virgin kraft pulp beaten to 19 SR and waste paper from postconsumer corrugated board, respectively. Also, the relative elongation of 0.4 to 0.5 % measured for chemi-mechanical pulp from rapeseed straw is much lower than that of 3.2 %

and 2.1 % for virgin kraft pulp and waste paper, respectively, determined by POTŮČEK *et al*. (2013). These results confirmed that chemi-mechanical pulp from rapeseed straw is not convenient for production of wrapping papers with low basis weight.

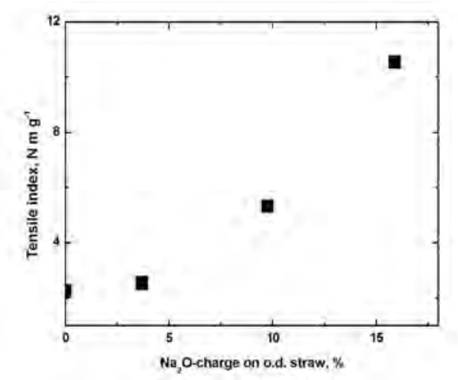

Fig. 3 Tensile index as a function of Na_2O charge.

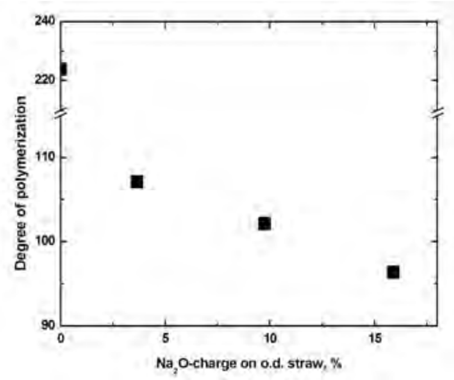

Fig. 4 Degree of polymerization as a function of Na_2O charge.

Moreover, the low tensile strength of chemi-mechanical rapeseed straw pulp was confirmed by rheosedimentation measurements. The rheosedimentation method based on observation and evaluation of the typical phenomenon of diluted pulp slurry with appropriate papermaking properties during their sedimentation was described in details by MILICHOVSKÝ and ČEŠEK (2004). Pulp slurries containing fibres with positive papermaking properties are characterized by slow rheosedimentation velocity which usually decreases with increasing degree of beating. For example, FIŠEROVÁ *et al*. (2009) reported the rheosedimentation velocity of 1.8 mm s^{-1} for bleached pulp from a blend of hardwoods, while MILICHOVSKÝ and ČEŠEK (2004) measured the rheosedimentation velocity of 1.2 and 1.7 mm·s^{-1} for sulphate bleached softwood pulp made from a blend of spruce and pine and bleached spruce pulp, respectively. Also, for soda pulp cooked from rapeseed straw the rheosedimentation velocities of 4.75 and 1.09 mm·s^{-1} were determined in case of unbleached unbeaten pulp and pulp beaten at 66 SR, respectively (POTŮČEK, MILICHOVSKÝ 2011). In case of chemi-mechanical pulp, however, the rheosedimentation velocity increased within the limits of 37 to 116 mm·s^{-1} with increasing Na_2O charge. Thus, it was confirmed that the fibres of chemi-mechanical pulp in suspension reveal low hydration ability resulting in very low tensile strength of pulp handsheets.

The degree of polymerization is directly proportional to the chain length of cellulose and has an impact upon some properties of pulp fibres such as mechanical characteristics. The degree of polymerization was determined viscosimetrically for unbeaten pulp from stalks. Figure 4 illustrates the effect of Na_2O charge upon the average degree of polymerization. The low values of degree of polymerization can be attributed to the presence of low molecular substances, mainly hemicelluloses, in chemi-mechanical pulps. Using conventional soda pulping (POTŮČEK, MILICHOVSKÝ 2011), the average degree of polymerization was found to be 917 for pulp from stalks of rapeseed straw (linie genotype Labrador). Similarly, ENAYATI *et al.* (2009) measured the degree of polymerization ranging of 1,408 to 1,579 for soda pulp cooked from canola stalks. For comparison the degree of polymerization of 396, 599, and 371 was also determined for beech unbleached kraft pulp, unbleached kraft pulp from softwood, and bleached kraft pulp from softwood, respectively. The low value of the degree of polymerization in case of beech pulp corresponds with short fibre length and also can be ascribed to the presence of hemicelluloses in pulp.

CONCLUSIONS

The results obtained in the scope of our study proved that, owing its papermaking properties exhibiting slight tensile strength, the chemi-mechanical pulp from rapeseed straw is not sufficient for the production of common papers manufactured from chemical pulps cooked from softwood.

Nevertheless, the preliminary results obtained offer a possibility to utilize chemi-mechanical pulp from rapeseed straw, at least partially, in the pulp and paper industry, *e. g.*, in a blend with softwood or hardwood pulps to manufacture moulded fibre products. With respect to current knowledge on chemi-mechanical pulping of rapeseed straw, further studies should be developed to confirm the suitability of rapeseed as a future non-wood fibre source. Besides chemical pulping of rapeseed straw, chemi-mechanical and enzymatic-mechanical pulping offer another possibility of rapeseed straw treatment. Hence, further studies should be aimed at these processes.

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