COMPARISON OF HARDWOOD KRAFT PULP FIBRE CHARACTERISTICS AND TENSILE STRENGTH

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Fibre characteristics of kraft pulps from hornbeam, birch, poplar, beech, oak and black locust, namely fibre strength (FS number), fibre length (L number) and bonding ability (B number), were determined by the Pulmac Zero-Span Tester. The fibre strength and fibre length of hardwood kraft pulps increased in the following sequence: black locust pulp < oak pulp < beech pulp < poplar pulp < birch pulp < hornbeam pulp. The influence of laboratory beating on FS number and L number of hardwood kraft pulps is analogous; an increased beating degree reduces slightly these fibre characteristics. On the other hand, the bonding ability of hardwood kraft pulps increased in the sequence: hornbeam pulp < birch pulp < poplar pulp < beech pulp < oak pulp < black locust pulp. With increasing the beating degree, B number increased in the whole range of beating degree, unlike FS number and L number. The tensile index increased in the following sequence: black locust pulp < oak pulp < beech pulp < poplar pulp < birch pulp < hornbeam pulp. The tensile index depends especially on the FS number and L number of hardwood kraft pulps. The lower FS number and L number of beech, oak and black locust kraft pulps are compensated, to some extent, by a higher B number.

Keywords: kraft pulp, hardwood species, beating, fibre strength, fibre length, fibre bonding ability, tensile index

INTRODUCTION

Hardwood pulps are used in printing and writing papers contributing to improved printability, sheet bulk, opacity and surface smoothness. Their applications usually comprise fine papers, printing papers and art papers. The properties of fibres and other raw materials influence the properties of the end products. The successful conversion of pulp into a marketable product depends on the original fibre characteristics and the response of fibres to processing variables. The properties of the raw wood material and the process of fibre separation have a significant influence on the properties of the produced fibres.

The fibre structure of various tree species determines the properties of the paper. Because of the great variety of wood species, the physical properties of a piece of paper from one species will often be markedly different from a similar piece of another species although processing conditions may have been identical. At present, the paper industry should rely much more on the currently less desirable hardwood species to better exploit the available fibrous raw material. In the paper production process, wood fibres keep their original structure. In order to improve the utilisation especially of the less used tree species, the fibre properties contributing to the required properties of paper should be better known.

The physical properties of paper sheets made from cellulosic fibres are dependent on fibre morphology. Morphological properties include fibre length, fibre width and cell wall thickness. These vary a lot among wood species, annual growth rings, different stem parts, being also affected by the growth conditions.[1] In a single pulp sample, the morphological properties of fibres vary a great deal. For example fibre length affects tensile strength, breaking strain and fracture toughness of dry paper, being important for wet web strength.[2] Chemical variation of pulp fibres has no influence on sheet strength. Hardwood fines (parenchyma cells) are detrimental to burst and tensile strength.

Vessel elements, in amounts originally found in typical hardwood furnishes, have no effect on tensile strength.[3]

Single fibre strength is very important to paper strength.[4] Also, the ability of the fibres to swell and form inter-fibre bonds is important for the strength of paper. Fibre strength may decrease in mechanical and chemical treatments, when fibre components, especially cellulose, are degraded. In the pulp and paper industry, zero-span tensile strength testing of paper or pulp handsheets with the nominal zero-span tester is often considered as an indicator of mean fibre strength.[5]

Fibre flexibility of hardwood kraft pulps is the key to the development of tensile and burst strength, as well as to the development of the paper properties that affect printing. Tear strength increases with an increase in fibre length, except at higher-than-normal levels of bonding, where increased fibre length can reduce tear strength. Increases in vessel and ray content correlate with lower strength properties, though studies differ as to their relative impact. Increases in wood cellulose content correlate positively with pulp yield and fibre strength, whereas increases in lignin content correlate negatively with these two properties.[6]

The relation between the fibre characteristics and the pulp-sheet properties of 5-year old trees of *Leucaena leucocephala* showed that cell-wall thickness and fibre length had the greatest influence on strength properties of unbeaten pulp. After beating, their influence was largely evident, as indices of their derived morphology. However, the regression equations showed that it is possible to fully categorize the performance of pulp-sheet properties on a single morphological factor.[5]

Nowadays, a widely used method for fibre strength characterisation is the so-called zero-span tensile test, in which the tested paper strips and, consequently, a given fibre is clamped at zero span of the tester jaws. This test has already been described and analysed by several authors.[8-13] Usually, a Pulmac tensile tester is used in such investigations. The fibre strength (FS number) determined in a zero-span test is not a fundamental measure of fibre strength, but is an indicator. The L number, determined by comparison of wet short span to wet zero span tensile strength is a measure of the fibre length. B number, the ratio of dry short span to wet short span tensile strength is a measure of the degree of fibre bonding. A certain influence on FS number has bonding strength of fibres in a dry sheet. Cowan[12-14] found that the effect of bonding can be eliminated by rewetting the sheet.

The objective of this work is to evaluate the relationships between fibre characteristics and tensile strength of kraft pulps from six hardwood species grown in Slovak Republic.

EXPERIMENTAL

Materials

The hardwood chips included oak (*Quercus robur L.*), birch (*Betula alba L.*), hornbeam (*Carpinus betulus L.*), black locust (*Robinia pseudoacacia L.*), beech (*Fagus silvatica L.*) and poplar (*Populus alba L.*) of industrial grade. The natural dirt was removed (TAPPI test method T 265 cm-99) from the chips mixture. The chips with dimensions of 20x20x30 mm were screened and used for laboratory cooking experiments.

Method

Laboratory kraft cooking

Kraft cooking was carried out in a 15 L recycle digester simulating CBC kraft technology. The laboratory cooking system consists of three accumulators, on-line alkali measuring equipment, three pumps, three heaters and two coolers. The charge of air dry chips was of 8.53 kg with a moisture content of 38.7%. The conditions of warm liquor filling process were as follows: 28 min, 115 °C, EA as NaOH – 33 g/L, pressure – 7 bar. The conditions of cooking process were the following: 63 min, 170 °C, EA as NaOH – 28.1 g/L, sulfidity – 25%, pressure – 10 bar. After the cooking process, the chips were then taken out and defibrated in a laboratory defibrator. Afterwards, the pulp samples were screened using a Somerville screen with 0.15 mm slot size; washing was done during this stage.

Pulp properties

The kappa number of hardwood kraft pulps (15-17) was determined according to ISO standard 302. The intrinsic viscosity number of hardwood kraft pulps (1000-1130 cm^3/g) was determined according to ISO standard 5351/1.

The hardwood kraft pulps were beaten in a laboratory Jokro mill to 20, 30, 40 and 50 °SR, according to ISO 5264-3. The beating degree was determined according to ISO 5267-1 standard. The test sheets (80 g/m^2 and 60 g/m^2, respectively) were prepared according to ISO 5269-2 and tensile index was determined according to ISO 1924-2 standard.

The zero-span tensile strength of hardwood kraft pulps was measured with a Pulmac Inc Zero-Span 1000 apparatus according to ISO

15361:2000 standard. The results were expressed as FS number, L number and B number:

FS number (N/cm) = Avg. > 10 wet zero-span tensile tests normalized to 60 g/m^2.

L number (%) = Avg. > 10 re-wet short (0.40 mm) span tensile tests/Avg. > 10 re-wet zero span tensile tests.

B number (%) = Avg. 10 dry short (0.40 mm) span tensile tests/Avg. 10 re-wet short span (0.40 mm) tensile tests.

RESULTS AND DISCUSSION

Figures 1, 2 and 3 show differences in FS number, L number and B number between oak, birch, hornbeam, black locust, beech and poplar kraft pulps and differences caused by pulp beating. FS numbers of hardwood kraft pulps increased by beating to 25 °SR. This observation is based on the fact that, by swelling and mild low consistency beating, curled fibres are straightened, more fibres are clamped and thus FS number increases.[15] Increasing beating degree over 30 °SR has only a minor influence on the FS number and L number of all hardwood species kraft pulps, these parameters slightly decreasing by beating (Figs. 1 and 2).

The FS number and L number of hornbeam, birch and poplar kraft pulps are higher, in the whole range of beating degree, compared to beech, oak and black locust kraft pulps. This is a consequence of the longer fibres of hornbeam, birch and poplar kraft pulps, when compared to the beech, oak and black locust kraft pulp fibres.

Figure 3 shows the dependence of B number on the beating degree of hornbeam, birch, poplar, beech, oak and black locust kraft pulps. With increasing the beating degree, B number increases in the whole range of beating degree, unlike FS number and L number (Figs. 1 and 2). The fibre bonding ability of hardwood kraft pulps, expressed as B number, strongly increases by beating. The B numbers of black locust, oak and beech kraft pulps are higher in the whole range of beating degree than those of hornbeam, birch and poplar kraft pulps.

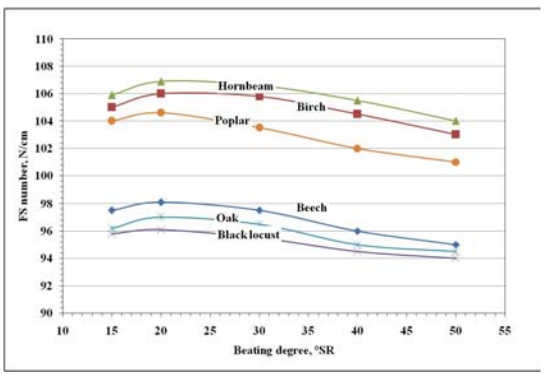

Figure 1: Influence of laboratory beating on FS number of hornbeam, birch, poplar, beech, oak and black locust kraft pulps

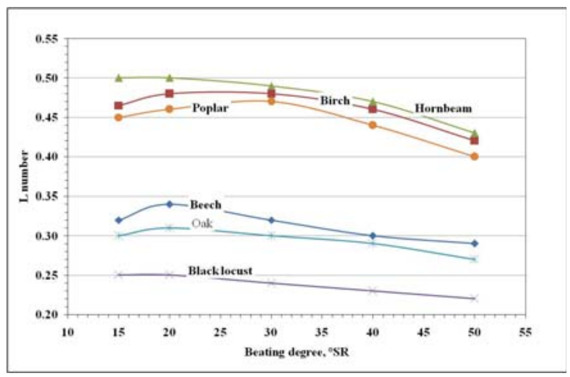

Figure 2: Influence of laboratory beating on L number of hornbeam, birch, poplar, beech, oak and black locust kraft pulps

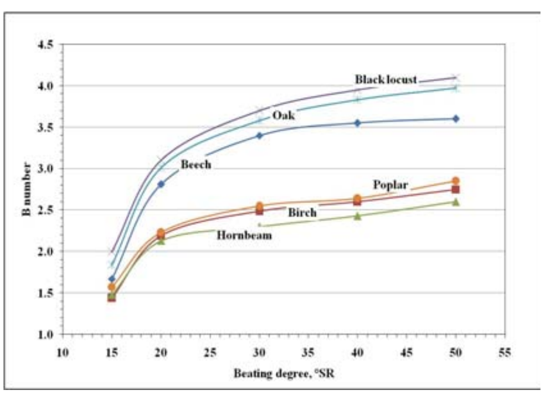

Figure 3: Influence of laboratory beating on B number of hornbeam, birch, poplar, beech, oak and black locust kraft pulps

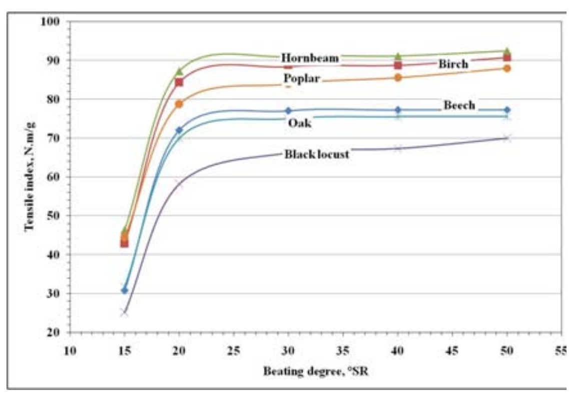

Figure 4: Dependence of tensile index on beating degree of hornbeam, birch, poplar, beech, oak and black locust kraft pulps

At 30 °SR, the B number of black locust, oak and beech kraft pulps was approximately 50% higher than that of poplar, birch and hornbeam kraft pulps. This is a consequence of the higher bonding ability of the shorter fibres of beech, oak and black locust kraft pulps, when compared to poplar, birch, and hornbeam kraft pulp fibres.

Figure 4 shows the dependence of tensile index on the beating degree of hornbeam, birch, poplar, beech, oak and black locust kraft pulps. With increasing the beating degree, the tensile index of all pulps increased. The tensile index of hornbeam kraft pulp was the highest in the whole range of beating degree. A little lower was the tensile index of birch and poplar kraft pulps. The tensile index of beech and oak kraft pulps was much lower in the whole range of beating degree than those of birch and poplar kraft pulps. However, the tensile index of black locust was the lowest in the whole range of beating. The development of hornbeam, birch, poplar, beech, oak and black locust kraft pulps tensile index dependency on beating degree (Fig. 4) is analogous to the dependencies of B number on beating degree (Fig. 3). The higher tensile index of hornbeam, birch and poplar kraft pulps is mainly caused by higher fibre strength (FS number) and fibre length (L number), as shown in Figs. 1 and 2.

Figure 5 shows the dependence of tensile index on the B number of hornbeam, birch, poplar, beech, oak and black locust kraft pulps at various beating degrees (15, 20, 30, 40 and 50 °SR). With an increasing beating degree, B number and tensile index simultaneously increase. The tensile index of hornbeam, birch and poplar kraft pulps at a 2.5 B number was higher (84.0-91.5 N.m/g) than that of beech, oak and black locust kraft pulps (40.5-64.0 N.m/g). An equal tensile index of the tested pulps was achieved at different B numbers, *e.g.* at a tensile index of 70 Nm/g, the B number of hornbeam pulp was of 1.83, of birch pulp – 1.9, of poplar pulp – 2.03, of beech pulp – 2.43, oak pulp – 2.68 and of black locust pulp – 4.18. The B number of hornbeam, birch and poplar pulps at equal tensile index was lower than that of beech, oak and black locust kraft pulps. However, the FS number and L number of hornbeam, birch and poplar pulps are higher at equal beating degree and, therefore, even at low B number tensile index is high.

The relationships shown in Figures 1-5 indicate that the tensile index, which is changing with the beating degree, depends on fibre properties. Fibre characteristics depend on wood species and cooking conditions. The compared pulps from different hardwood species were prepared under basically equal cooking conditions. The differences in fibre characteristics of the evaluated hardwood kraft pulps are explained by the different properties of the wood species used for pulp preparation.

Figure 6 shows an overall evaluation of the influence of fibre characteristics on the tensile index of various hardwood kraft pulps at 30 °SR. The tensile index of hardwood kraft pulps decreases from 91.0 to 66.2 N.m/g, *i.e.* by about 25%. Tensile index decreases in the following sequence: hornbeam pulp > birch pulp > poplar pulp > beech pulp > oak pulp > black locust pulp. The fibre strength of hardwood kraft pulps at the same beating degree, determined as FS number, decreases from 106.6 to 95.5 N/cm, *i.e.* by about 10%. FS number decreases in the sequence: hornbeam pulp > birch pulp > poplar pulp > beech pulp > oak pulp > black locust pulp.

The fibre length of hardwood kraft pulps at 30 °SR beating degree, expressed as L number, decreases from 0.49 to 0.24, *i.e.* by about 51%. The highest fibre length is that of hornbeam kraft pulp and the lowest – of black locust kraft pulp.

The fibre bonding ability of hardwood kraft pulps at 30 °SR beating degree, determined as B number, decreases from 0.37 to 0.23, *i.e.* by about 37.8%. B number decreases in the sequence: black locust pulp > oak pulp > beech pulp > poplar pulp > birch pulp > hornbeam pulp.

The tensile index of hardwood kraft pulps decreases in the same sequence as FS number and L number. The decrease of these fibre characteristics is compensated, to some extent, by the higher B number of hardwood pulps. The results show that the tensile index of hardwood kraft pulps was more affected by fibre length than by fibre strength.

The highest tensile index of hornbeam kraft pulp is related to the highest FS number (106.6 N/cm) and L number (0.49) and the lowest B number (2.3). On the other hand, the lowest tensile index of black locust kraft pulp is related to the lowest FS number (95.5

N/cm) and L number (0.24) and the highest B number (3.7).

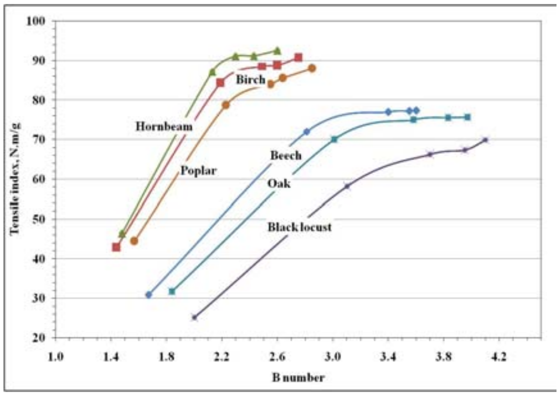

Figure 5: Dependence of tensile index on B number of hornbeam, birch, poplar, beech, oak and black locust kraft pulps

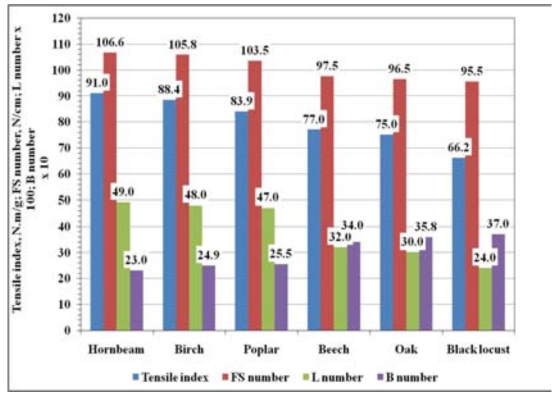

Figure 6: Tensile index, FS number, L number and B number of hornbeam, birch, poplar, beech, oak and black locust kraft pulps at 30 °SR

CONCLUSIONS

The tensile index of different hardwood species kraft pulps depends on fibre strength and length characteristics, as well as on fibre bonding ability. The results show that the higher tensile index, which decreases in the sequence: hornbeam pulp > birch pulp > poplar pulp > beech pulp > oak pulp > black locust pulp, is related to a higher FS number and L number characterising fibre strength and fibre length. L number affected more tensile index than FS number. Higher tensile index, FS number and L number were recorded for hornbeam kraft pulp, than for birch kraft pulp and poplar kraft pulp. The lower FS number and L number of beech, oak and black locust kraft pulp is compensated, to some extent, by the higher B number of these pulps.

The influence of laboratory beating on the FS number and L number of kraft pulps is analogous; increasing the beating degree reduces slightly these fibre characteristics. On the other hand, the B number of hardwood kraft pulps increased with an increasing beating degree in the whole range of the beating degree.

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