EFFECT OF ADDING SECONDARY FIBERS TO KRAFT PULP ON STRENGTH PROPERTIES AND AIR RESISTANCE

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Received December 6, 2011

This paper deals with the utilization of secondary fibers as one of possible furnishes for the production of sack paper. The effect of the addition of waste papers to the virgin kraft pulp upon the tensile properties, paper porosity, and bonding ability was investigated. Waste papers, namely postconsumer corrugated board (quality grade A5), and cut-offs obtained from never-used corrugated board (quality grade A6), were chosen as secondary fibers. The results obtained were evaluated using statistical methods and compared with those reported for sack papers. The addition of waste papers to virgin kraft pulp increased air resistance, but lowered tensile strength from 7.99 km for virgin kraft pulp to 3.83 and 4.13 km for waste paper of quality grades A5 and A6, respectively.

Keywords: waste paper, kraft pulp, tensile energy absorption, air resistance

INTRODUCTION

At present, mainly in densely populated regions with high paper consumption per capita, the paper industry is the exclusive user of recovered paper as a secondary raw material. Some paper and board grades can use exclusively recycled fibers. Some grades, for example liner, use blends of recycled and virgin fibers with various proportions of recycled fibers in the furnish depending on the paper or board grade. The yields of recycled fiber pulps for packaging papers and board are high, as these are mostly brown recovered papers processed without deinking.[1,2]

Furthermore, the demand of paper has been continuously increasing at a pace much faster than the availability of fibers from natural sources. Recycling of waste paper, after its intended use, has been found to be more economical and eco-friendly. Without recycling, the fiber supply from natural sources would not be sufficient to keep up with the demand. Recycling efficiency can be increased further by selecting the recovered paper based on proper grade and reusing high value papers.[3]

Each time paper is recycled, some of the longer (chemical pulp) fibers are shortened, and they generally lose their flexibility and bonding ability due to hornification. It is further observed that deinked pulp suitable for use in printing papers usually imparts special properties to the finished papers compared with papers made from wood pulp. These properties comprise increased opacity, lower curling tendency, less fuzziness, better formation, better retention of size and fillers.[4]

With the increasing use of secondary fibers, it has become more important to know how the fiber affects the properties of the product.[5–7] The decrease in strength properties can be mainly attributed to a change in the physical/chemical surface condition of the fibers, which allows the formation of fewer hydrogen bonds. With repeated recycling, individual fibers also lose some of their original virgin wet plasticity and thus provide less bonding area between them.[5] Some authors[6] report that the decrease in strength is positively correlated with the extent of beating that fibers undergo during their first use, particularly for softwoods. Ellis and Sedlachek[7] found that repeated drying reduces the fiber strength and fiber perimeter by about 7%, however, the fiber-fiber bond strength of recycled fibers is equivalent to that of virgin fibers, and that the relative bonded area dominates the observed strength loss in recycled sheets.

Our study has been motivated by the contamination of the press rolls and the first dryer cylinder, which can be sometimes an unfavourable phenomenon during sack paper production. Generally, the contaminants cause significant operating problems, such as picking and sticking of the paper web because of adhesion to the cylinder surface. A layer of contaminants on the dryer cylinder surface not only results in lower heat transfer, but also requires lower than optimum operating temperatures in order to counteract the effects of sticking and picking.

With respect to its utilization and also quick filling of powdered goods, strength and porosity are key features of sack paper. Hence, our study has been conducted to investigate the effect of adding recycled fibers to virgin kraft pulp upon the tensile strength and porosity of handsheets prepared under laboratory conditions, which differ mainly in the stock preparation and paper formation from the conditions in industry.

EXPERIMENTAL

Materials

The materials used for the papermaking experiments included: virgin unbleached kraft pulp (freeness of 11 °SR, kappa no. 39) cooked from softwood (spruce and pine); waste paper, namely postconsumer corrugated board (quality grade A5, *i.e.*, EN 643-4-02 and EN 643-4-03), and cut-offs obtained from never-used corrugated board (quality grade A6, *i.e.*, EN 643-4-01-02);[8] as well as the following additives: solution of aluminium sulphate (12% of H_2SO_4 and (3.5 ± 0.1)% Al_2O_3). 30% dispersion of acid size Sacocell KN 12A produced by Kemira, 2% solution of cationic potato starch EMCAT L50T, produced by Emsland (Germany).

Procedure

Before blending with a stock of the waste paper, the virgin kraft pulp was beaten at 1.7% consistency in a laboratory Valley beater until a freeness of 19 °SR was reached. Then mixtures of the virgin kraft pulp with the waste paper stock containing from 10 to 90% of waste papers (grades A5, A6, and combinations ¼ A5 plus ¾ A6, ½ A5 plus ½ A6, and ¾ A5 plus ¼ A6) were prepared.

The furnishes of sizing agent, starch, and aluminium sulphate, approximately equal to those applied in production of sack papers (8 kg of cationic starch, 3 kg of acid size, and 25 kg of $Al_2(SO_4)_3$ solution per 1 t of oven-dried pulp) were kept constant for experiments with waste papers. Using a handsheet former, handsheets having a basis weight of about 70 g m^{-2} were made.

Before measuring physical properties, the handsheets were conditioned for 24 hours at a temperature of (23 ± 2) °C and (50 ± 5) % relative humidity. Basic properties important for sack papers, namely strength properties and air resistance, were determined. The strength performance of actual paper sacks is best predicted by the tensile energy absorption of the paper, which is a measure of the paper's work to failure. The energy will then be absorbed by a combination of the tensile strength and the stretch in the paper.

The strength properties were measured using the tensile strength tester TIRA. The air resistance of handsheets was determined according to Gurley and expressed in seconds per 100 mL of air. For a given furnish of the waste paper, the strength properties were determined for twenty strips, while air resistance for four samples only. Relative elongation and rheosedimentation characteristics were also measured.

RESULTS AND DISCUSSION

The strength properties of the handsheets made of a mixture of virgin kraft pulp and secondary fibers were expressed by a tensile energy absorption index (*TEAI*). For quality grades A5 and A6, Figures 1 and 2 show the tensile energy absorption index as a function of the mass fraction of the waste paper in a blend of virgin kraft fibers and secondary ones. Since the data measured for all furnishes of waste paper to virgin kraft pulp showed a normal distribution, the average is a suitable statistical parameter, which is illustrated along with 95% confidence intervals. As the dependencies between *TEAI* (in J g^{-1}) and mass fraction of the waste paper, x, showed more or less a linear trend, the correlation equation in the form:

$$TEAI = a_0 + a_1 x \quad (1)$$

was chosen to fit the experimental data measured for quality grades A5, A6 and their combination. For a more synoptical comparison, only averages of the tensile energy absorption index are illustrated in Figure 3, when mixtures of A5 with A6 waste papers were tested.

Since the values of regression coefficients a_0 and a_1 represent an estimate of the real values, the 95% confidence intervals were also calculated and are summarized in Table 1.

As one can expect, the greatest value of the tensile energy absorption index equal to 1.78 J g^{-1} was attained for the virgin kraft pulp without addition of waste paper. For comparison, the sack paper produced by Mondi Štětí reaches 1.5 J g^{-1} in the paper machine direction and 2.6 J g^{-1} in the cross direction.[9]

Table 1
Regression coefficients in equation (1) along with their confidence intervals (C. I.)

Waste paper gade	a_0, J g^{-1}	95% C. I. of a_0	a_1, J g^{-1}	95% C. I. of a_1	r
A5	1.654	(1.616; 1.691)	–1.112	(–1.179; –1.105)	0.921
A6	1.765	(1.722; 1.809)	–1.179	(–1.252; –1.105)	0.907
Mixtures A5 + A6	1.561	(1.471; 1.651)	–1.110	(–1.277; –0.942)	0.951

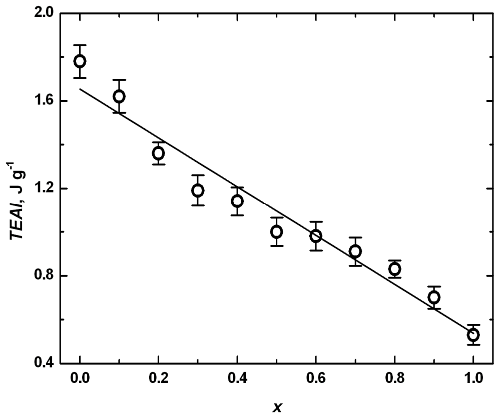

Figure 1: Effect of waste paper furnish on tensile energy absorption index for grade A5; solid line – eq. (1)

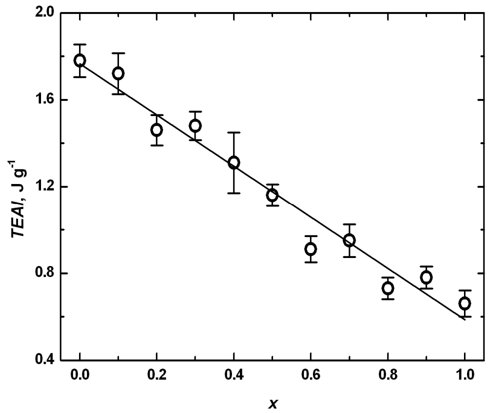

Figure 2: Effect of waste paper furnish on tensile energy absorption index for grade A6; solid line – eq. (1)

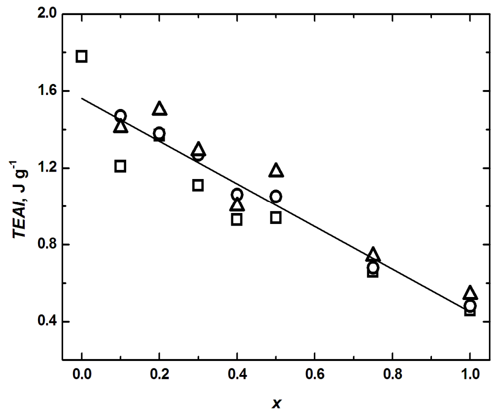

Figure 3: Effect of waste paper furnish on tensile energy absorption index for blend of A5 and A6; □ 75% A5:25% A6, ○ 50% A5:50% A6, Δ 25% A5:75% A6, solid line – eq. (1)

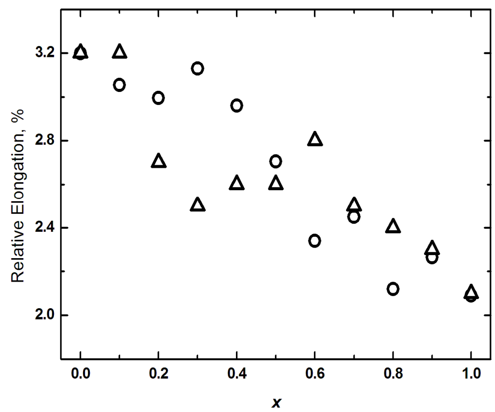

Figure 4: Effect of waste paper furnish on relative elongation; waste paper: Δ grade A5, ○ grade A6

The difference in the properties of virgin fibers and of recycled ones influenced the relative elongation of handsheets, which decreases from 3.2% for kraft fibers to 2.1% for secondary ones. The effect of the mass fraction of the recycled fibers on the relative elongation measured for both grades of the waste paper is shown in Figure 4. It should be noted here that the elongation increases the energy required to break the material. Therefore, in the dryer section the sack paper is microcrepped to give sufficient elasticity and porosity.

For comparison with the results obtained by other researchers,[10–12] strength properties were also expressed by the breaking length which had values of 7.99, 3.83, and 4.13 km for unbleached virgin kraft pulp beaten to 19 °SR, waste paper of quality grade A5, and waste paper of quality grade A6, respectively. Čabalová *et al.*[10] report for virgin pulp after the first beating a breaking length of 8.3-9.1 km. This pulp after eightfold recycling was characterized by the breaking length of 3.7-5.0 km, depending on drying temperature. For bleached kraft pulp prepared from hardwood blend having a beating value of 29 °SR, Geffertová and Geffert[11] measured the breaking length of 4.9 to 6.3 km. Nevertheless, by eightfold recycling, the breaking length dropped to 2.0-3.1 km. For waste paper, Verma *et al.*[12] found a breaking length of 3.9 km, which is in agreement with our results.

The presence of waste paper in the handsheets has an impact on their porosity (Figures 5-7). The influence of the mass fraction of the waste paper, x, on Gurley air resistance, GAR (in seconds per 100 mL of air) can be correlated in the form:

$$GAR = a_0 + a_1 x \quad (2)$$

It should be noted that higher values of Gurley air resistance correspond to handsheets with lower porosity. In Table 2, the regression coefficients from eq. (2) are summarized.

The air resistance of handsheets was measured only four times for each furnish of the waste paper to virgin kraft pulp. Therefore, the 95% confidence limits illustrated in Figures 5 and 6 were calculated using the Horn procedure of pivot measures recommended for small samples when sample size is between 4 and 20.[13,14]

An increase in the Gurley air resistance with increasing waste paper furnish can be ascribed to the presence of fines in the waste paper, on the one hand, and the presence of starch and its conversions applied during manufacture or pasting of the wavy board, on the other hand. While weighted average length of virgin kraft pulp fibers had a value of 2.24 mm and the arithmetic average length was 1.30 mm, the corresponding values measured for a sample of corrugated board were of 1.26 mm and 0.62 mm, respectively.

Table 2
Regression coefficients in equation (2) along with their confidence intervals (C. I.)

Waste paper grade	a_0, s	95% C. I. of a_0	a_1, s	95% C. I. of a_1	r
A5	2.9455	(2.473; 3.417)	5.758	(4.984; 6.532)	0.984
A6	3.230	(2.700; 3.758)	5.794	(4.926; 6.661)	0.981
Mixtures A5 + A6	4.989	(4.260; 5.718)	6.040	(4.681; 7.398)	0.901

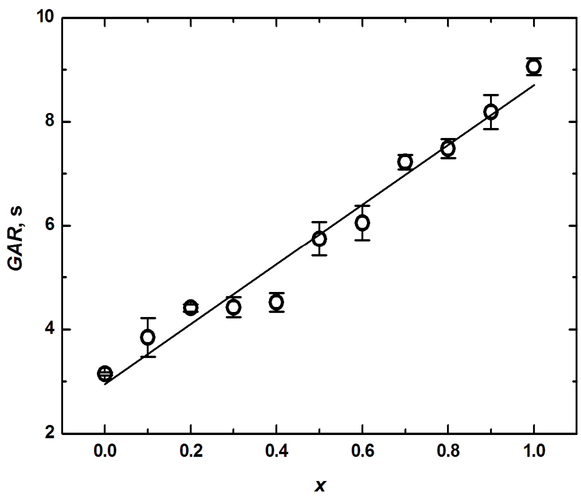

Figure 5: Effect of waste paper furnish on Gurley air resistance for grade A5; solid line – eq. (2)

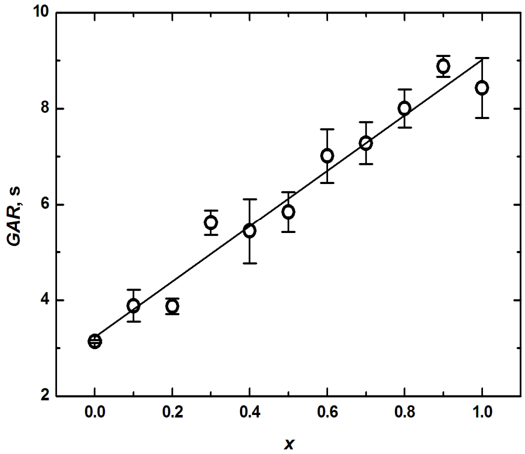

Figure 6: Effect of waste paper furnish on Gurley air resistance for grade A6; solid line – eq. (2)

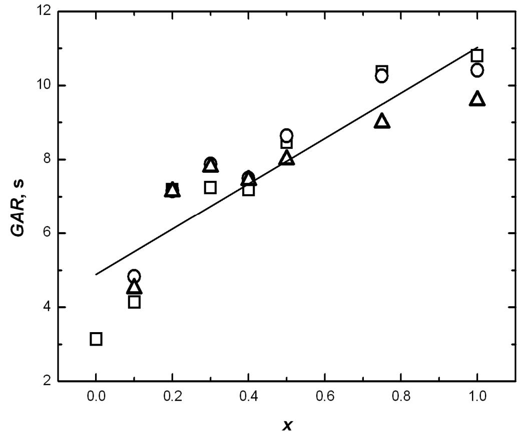

Figure 7: Effect of waste paper furnish on Gurley air resistance for blend of A5 and A6; □ 75% A5:25% A6, ○ 50% A5:50% A6, Δ 25% A5:75% A6, solid line – eq. (2)

Since contamination of the surface of the press rolls and the first dryer cylinder is sometimes an undesirable phenomenon during sack paper production, having a negative effect on runnability issues and lowered productivity of the paper machine, a rheosedimentation method was utilised for the evaluation of fiber bonding ability of the waste paper samples analysed here. Bonding and strength properties of pulp fibers are basic demands in a well-controlled papermaking process. Both these demands may be estimated by the so-called rheosedimentation method,[15] *i.e.*, by observation and evaluation of sedimentation of diluted pulp slurries on the basis of two parameters, the standard rheosedimentation velocity and the final concentration of sediment. Both parameters given in Table 3 were evaluated for kraft pulp, waste papers and their mixture. The results obtained show that the addition of waste paper to virgin sulphate fibers leads to a decrease in sedimentation and to an increase in sediment concentration. A low sedimentation velocity indicates better hydration ability of the mixtures of sulphate and secondary fibers. Our laboratory experiments on a paper machine confirmed all these observations. By adding secondary fibers to the pulp slurry, the adhesion tendency of wet paper sheets in the press section of the laboratory paper machine was evidently diminished.

Table 3
Results of rheosedimentation of pulp slurries

Pulp slurry	Sedimentation velocity, mm s^{-1}	Concentration of sediment, kg m^{-3}
Sulphate pulp beaten to 19±1 SR	7.33	2.44
Waste paper; quality grade A5	2.35	7.23
Waste paper; quality grade A6	2.40	8.26
Mixture of fibers*	1.06	4.83

*The mixture of fibers was composed of 70% unbleached sulphate pulp, 22.5 % of waste paper quality grade A6 and 7.5% of waste paper quality grade A5

However, the overall tensile strength of paper sheets depends upon the fiber strength and bonding strength. In spite of the fact that low rheosedimentation velocity appears as a positive factor, one can assume that the effect of recycling on the bonding contribution to the overall strength is considerably smaller than the effect of fiber strength contribution influenced by a loss in fiber coarseness, original virgin wet plasticity and fold endurance, and a change in fiber length.

CONCLUSION

By adding waste papers to virgin kraft pulp, we observed the following:

(i) the TEA index decreased from 1.78 J g^{-1} to 0.66 J g^{-1} for quality grade A6, and to 0.53 J g^{-1} for quality grade A5, the corresponding values of the tensile strength dropped from 7.99 km to 4.13 km for quality grade A6, and to 3.81 km for quality grade A5;

(ii) the air resistance, expressed in Gurley seconds per 100 mL of air, increased from 3.1 s to 8.4 s for quality grade A6, and to 9.1 s for quality grade A5.

In spite of the fact that the addition of secondary fibers to virgin kraft pulp leads to a decrease in strength properties and an increase in air resistance, the lower contamination of the press rolls and the first dryer cylinder, when a small amount of secondary fibers (up to 20%) is present in a blend with virgin fibers, would be a possible option of improving the runnability of the paper machine producing sack paper. Comparing both quality grades, it seems that grade A6 including cut-offs obtained from never-used corrugated board is more suitable for addition to kraft pulp fibers.

ACKNOWLEDGEMENTS: This paper was supported by the Ministry of Education, Youth, and Sports and Ministry of Culture of the Czech Republic under the Research Projects MSM0021627501 and NAKI DF11P01OVV028, respectively.

SYMBOLS

a_0, a_1 regression coefficient in eqs. (1) and (2) in J g^{-1} and s, respectively
GAR Gurley air resistance, s
r correlation coefficient
TEAI tensile energy absorption index, J g^{-1}
x mass fraction of secondary fibers

Abbreviations

C. I. confidence interval

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