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ADVANCED UTILIZATION OF RECOVERED FIBRES IN FLUTING AND TEST LINER

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ABSTRACT

Analysis of flexural rigidity, internal bond strength and porosity of paper offers a good picture about fluting and test liner furnish composition and necessary changes in fibre treatment. Evaluation of laboratory experiments by these three parameters made possible selection of suitable technology for treatment recovered fibres which is effective and universal for fluting and test liner manufacture from virgin and recovered fibres. An optimal technology exploits the natural bond potential of recovered fibres in combination with nanoparticle retention and drainage system. The first component of the nanoparticle retention and drainage system is a natural or synthetic cationic polymer for increase of dry strength. The second component is agent based on structured silicic acid. By application of an optimal combined recovered fibres treatment technology a CMT_{30} increase by 7-20%, SCT by 6-21% and burst strength by 7-38% was observed in dependence of semichemical pulp content in furnish (20-80%) while the porosity was unchanged. Laboratory experiments showed that by application of optimal technology at fluting production it is possible to reduce by 20-38% virgin fibres (semichemical pulp) in the furnish which is usually 25-70%. By application of this optimal technology of recovered fibres quality of test liner is increased from the T3 level to T2 level and simultaneously the semichemical pulp content in the furnish can be decreased from 20% to 5-0%. Treatment of recovered fibres just by refining without application of retention and drainage system or just application of the retention and drainage system does not result in significant improvement of fluting and test liner parameters.

KEY WORDS: recovered fibres, semichemical pulp, groundwood, refining, cationic starch, retention aids, fluting, test liner, porosity, mechanical properties

INTRODUCTION

Papers for corrugated layer and liner (fluting, test liner, liner) are construction materials of corrugated board which should fulfil two main functions: to protect the goods packed in boxes during handling, storing and transport of boxes and moreover render a printing surface for marking the manufacturing or trade company etc. On Fig. 1 and Fig. 2 is the cross section of corrugated board before and after compression. It can be observed on Fig. 2 that by applying an excessive pressure interfiber bonds are damaged by shear forces manifested by change of flute form (permanent deformation) and splitting. Both changes can be observed also on the liner.

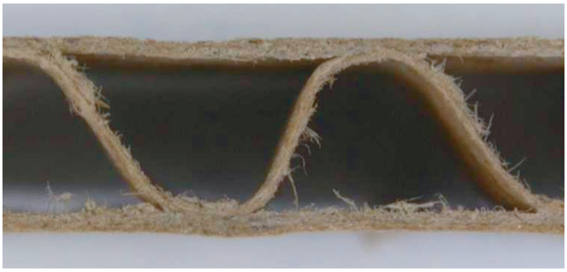

Fig.1: Cross section of corrugated board before a pressure test

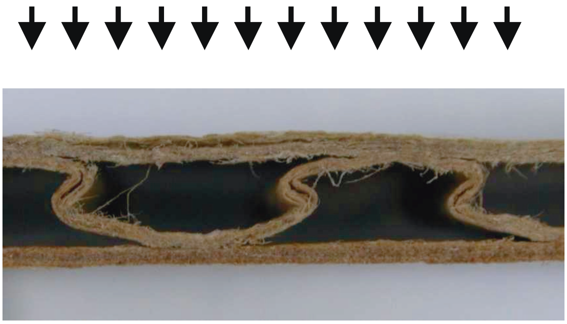

Fig. 2: Cross section of corrugated board after a pressure test – deformation and splitting

As compression of corrugated board is resulting not only in deformation of both construction materials but also in splitting, it was proposed to apply for calculating strength parameters of construction materials basic physical and mechanical properties of papers - flexural rigidity, internal bond strength and porosity (Vullierme and Serra-Tosio 2000).

In manufacturing construction materials (fluting, test liner, liner) virgin and recovered fibres are used. The furnish composition depends on the standard of manufacturing technology and requirements of converters on qualitative properties of the final product. Refining of fibres can be considered as the most important step in the manufacturing process, which can influence raw material composition, energy consumption, manufacturing costs and runnability of the paper machine. For the manufacturer and converter of paper qualitative aspects are most important. This was the reason for developing suitable refiners and tackles (Baker 1995, Lumiainen 1997). There are some important factors, which influence refining results and quality of paper (Naujock 2001, Ortner 2004, Ortner and Hietanummi 2004). Energy consumption and refiner tackles design influence processing of fibres and furnish of paper fibre raw materials. The way of energy exploitation is the base for understanding the refining process. In order to achieve low energy consumption in refining, the energy consumption for transport of the stock through the refiner and for revolving the refiner plate in water should as low as possible. Energy consumption for revolving the refiner plates in water is to large extent influenced by revolution speed and diameter of plate. Specific loading of the refiner tackle edges SEL (Specific Edge Load) is widely accepted (Wultsch and Flucher 1958). Later was developed an equation related to stress and number of impacts (Leider and Rihs 1977, Leider and Nissan 1977). For the sake of simplification the theory of cutting edges is applied. According this theory the energy applied on the cutting edge is considered as most critical as it has seven times higher effect than the width of the bar. Mathematical expression of this theory applying net power demand of the motor Pn and cutting speed Ls is described by the equation /1/:

$$SEL = (Pt - Po) / Ls = Pn / Ls, \quad (1)$$

where Pn (kW) is the difference of the total Pt and pumping Po power ("on water"). The cutting speed Ls (km/s) is calculated from the number and length of bars and velocity of bar revolution. The specific net energy consumption Wn (kWhr/t) in fibre refining is given by the equation /2/:

$$Wn = Pn / m, \quad (2)$$

where m (t/hr) is dry fibre flow through the refiner. While a high SEL value expresses the tendency of fibre cutting at low values fibrillation of fibres takes place. The value of SEL (J/m) in the equation /1/ is suitable to transform with the so called modification factor Mf, which includes geometry of the refining bars resulting in a complete information about the refining process. From equation /1/ equation /3 / is derived where MEL (J/m) is the so called modified edge load:

$$MEL = Mf \, . \, SEL \quad (3)$$

Modification factor Mf for which relation /4/ is valid contains angle of bars α (half of cutting angle β), bar width b (mm) and grooves width g (mm):

$$Mf = (1/ (2 \, tg \, \alpha)) \, . \, ((b+g)/b) \quad (4)$$

In laboratory scale experiments influence of recovered fibres refining, nanoparticle retention and drainage system application and of groundwood furnish on physical and mechanical properties of papers prepared from NSSC (Neutral Sulphite Semichemical) pulp and recovered fibres was investigated with the aim to reduce semichemical pulp content in fluting and test liner furnishes of various qualitative classes.

MATERIALS AND METHODS

Virgin fibres: NSSC pulp (hardwood mixture, 27°SR beating degree, 12.8% fines content), groundwood (spruce, 52°SR, 20.1% fines content).

Recovered fibres: from waste paper classes 1.02, 1.04, and 1.05 according STN EN 643 (27 °SR beating degree, 18.3% fines content).

Nanoparticle retention and drainage system: cationic component (dry strength increasing agent – potato starch PerlBond 930) and an anionic component – colloidal silicic acid Composil BMA 780.

Commercial samples: fluting based on NSSC and soda-AQ (anthraquinone) semichemical pulp (basis weight 112-155 g/m^2, quality A).

Recovered fibre pulp was refined in a fibrillation mode in a conical refiner Jylhä 0 at SEL 0.6 J/m corresponding to MEL 1.2 J/m. Refining increased beating degree from 27°SR to 31°SR and fines content from 18.3% to 19.9%.

Virgin fibres – NSSC pulp and recovered fibres furnish with virgin fibres content 20-80% was prepared by following technologies:

A – conventional technology using non-refined recovered fibres,
AK – conventional technology with addition of nanoparticle retention and drainage system,
AD10K – AK technology with addition of 10% groundwood,
B – modified technology with using refined recovered fibres,
BK – modified technology with addition of nanoparticle retention and drainage system,
BD10K – BK technology with addition of 10% groundwood.

Potato starch in an amount of 1.2% on recovered fibres and a corresponding amount of NSSC pulp was added to the furnish. The furnish of virgin and recovered fibres was processed 30 s by shear strength 370 s^{-1} and after diluting commercial Compozil BMA 780 was added (0.4% on fibres). From this furnish laboratory hand sheets of 127 g/m^2 basis weight were prepared on a Rapid-Köthen sheet making machine ISO 5269-2. After conditioning at 23°C/50% R.H. the following strength properties were measured: burst strength (ISO 287), Concora medium test CMT (ISO 7263), SCT (Short Span Compression Test) according ISO 9895, bending resistance (TAPPI method T 556 pm-95), internal bond strength (Scott Bond Energy) according TAPPI T 506 wd-83, calliper (ISO 534), basis weight (ISO 536) and Gurley porosity (ISO 5636-5).

RESULTS AND DISCUSSION

Fluting quality is evaluated according utilisation: for transport packaging SCT in machine direction is measured, for storing packaging SCT in cross direction and for both applications CMT is tested in machine direction. Parameters CMT and SCT were measured directly and also calculated using equations /5/ and /6/ (Vullierme and Serra-Tosio 2000):

$$CMT = k'.\ Co^{1/3}.\ R_f^{2/3}.\ (1-\varepsilon)^{0.76} \quad (5)$$

$$SCT = k\ .R_f^{1/3}.Co^{2/3}.\ (1-\varepsilon)^{0.87} \quad (6)$$

Cohesivity Co was determined as internal bond strength (Scott Bond Energy). In determination of flexural rigidity (R_f) was used a two point bending resistance method with 15° bending angle at 25 mm clamp and blade distance. Coefficients k and k´ depend on applied method and conditions of determination flexural rigidity. Porosity ε expresses the relative pore volume by application of paper apparent density (ρ_z) and fibre wall density according equation /7/:

$$\varepsilon = 1 - (\rho_z/1530) \quad (7)$$

Correlation coefficients of CMT and SCT values determined by direct measurements and by calculation are closed to one. Good correlation and dependence of both strength parameters CMT and SCT enables calculation of CMT without a comparatively tedious preparation of flute followed by direct CMT measurement. Relationship between CMT_{30} and SCT determined for commercial A quality flutings based on NSSC (blue rhombus) and soda-AQ (SAQ) semichemical pulp (red rectangles) is presented on Fig. 3. For comparison on the same figure relationship for fluting based on recovered fibres published in (Nahrath 2004) is shown (green triangles).

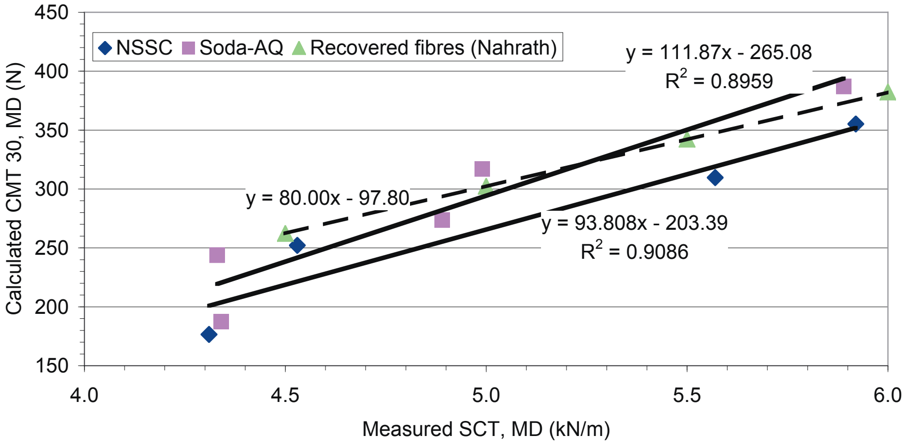

Fig. 3: Prediction of commercial flutings CMT_{30} in machine direction

Influence of virgin and recovered fibres treatment conditions and influence of virgin fibres content in the paper was evaluated by calculating CMT_{30} and SCT and by determination of burst index. Fig. 4 shows the relationship between calculated CMT_{30} and semichemical pulp content in mixture with recovered fibres, which were prepared by technology alternatives A, AK, B and BK as well as with addition of 10% groundwood (alternatives AD10K and BD10K).

With increase of semichemical pulp content in the furnish CMT_{30} increases in all fibre technology alternatives. Increase of semichemical pulp content from 40% to 50% resulted in CMT_{30} increase approximately by 5.5% in treatment technology alternatives A, B, and BK. At a constant 40% content of semichemical pulp by application of various technology alternatives increase of CMT_{30} can be expressed by the following order: A (182 N) = AK = AD10K < B (197 N) = BD10K < BK (215 N). Numbers in brackets are CMT_{30} values of 127g/m^2 test sheets. Refining of recovered fibres (technology B) increased CMT_{30} approximately by 10%. Influence of the retention and drainage system is more significantly expressed in combination with refining of recovered fibres resulting in CMT_{30} increase by 20% (technology B) when compared with treatment technology A. The assumed increase of CMT_{30} by addition of groundwood was not achieved.

Refining of recovered fibres or addition the nanoparticle retention and drainage system alone increased internal bond strength only marginally. Obviously mild refining of recovered fibres reverts some of the changes caused on the surface of fibres by drying making possible creation of additional hydrogen bonds. Consequently, more fibre to fibre bonds can be created by starch. Mild refining of recovered fibres followed by application of a nanoparticle retention and drainage system containing starch is resulting in a synergy effect.

Combination of fibrillation refining of recovered fibres with nanoparticle retention and drainage system resulted in significant CMT_{30} increase enabling reduction of semichemical pulp input in fluting quality class F1 and F4 production as shown in Fig. 4.

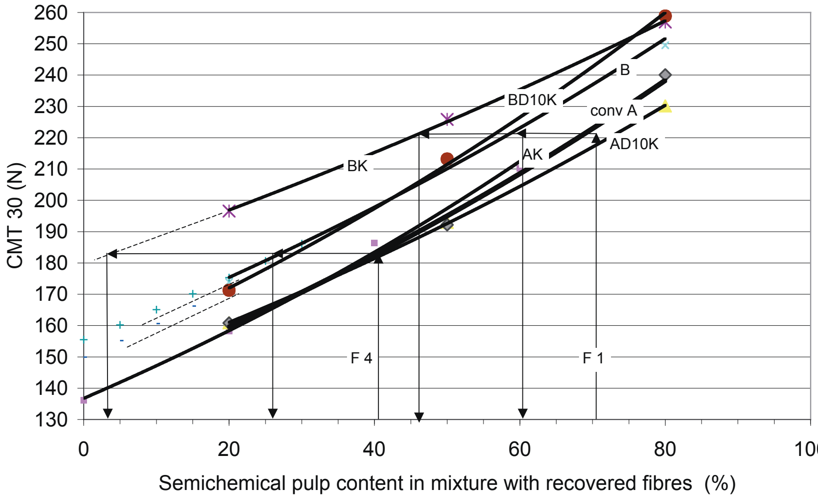

Fig. 4: Influence of technology on semichemical pulp input and on CMT_{30} of paper

To achieve required CMT_{30} value of fluting quality class F1 (223 N) by conventional technology A 70% semichemical pulp, by modified technology B 60% and by application of technology BK only 47% semichemical pulp is required. Analogically it is possible to determine that to achieve quality F4 (182 N) by application of conventional technology A 40% content of semichemical pulp in fluting is required but in case of modified technology B 25% and by application of technology BK just 2% of semichemical pulp is required.

Influence of fibre treatment technology alternative A, B, and BK with regard to semichemical pulp content in papers (Fig. 4) necessary to achieve the required and porosity of fluting quality class F1 to F5 is summarised in Tab. 1. In all fluting types required CMT_{30} semichemical pulp input decreased significantly (by 20 to 38%) at application of optimal technology, i.e. combination of recovered fibres refining with the retention and drainage system (technology BK). In F4 fluting preparation by optimal technology BK semichemical pulp input can be reduced from 40% to 2% without CMT_{30} decrease. Reduction of semichemical pulp content in fluting F1 to F5 furnish in case of recovered fibres refining (technology B) represents 10% to 15%. Again largest semichemical pulp reduction was in case of fluting F4. It is evident from these results that in production of F4 fluting application of technology B and BK gives most advantage. An advantage of combined technology BK is besides lower semichemical pulp input preservation of required paper porosity. Preservation of original porosity (achieved by technology A or BK) which is necessary for adhesive absorption in corrugated board manufacture is not possible by application of technology B.

Refining of recovered fibres increases CMT value but reduces porosity of the sheet. Addition of the nanoparticle retention and drainage system improves porosity (reduces Gurley test level) and makes possible application of recovered fibres refining without impairing porosity (Tab. 1).

Tab. 1: Semichemical pulp content in fluting quality F1 to F5 prepared by technology A, B and BK

Fluting quality	CMT_{30} requirement (N)	*Gurley porosity requirement (s)*	Conventional technology **A**	Modified technology **B**	Modified technology **BK**
F1	223	*Gurley (s)*	70 *57*	60 *58*	47 54
F2	208	*Gurley (s)*	60 *49*	49 *52*	40 *50*
F3	195	*Gurley (s)*	50 *42*	40 *48*	20 *40*
F4	182	*Gurley (s)*	40 *35*	25 *42*	2 *34*
F5	165	*Gurley (s)*	25 *28*	10 *36*	0 *33*

Test liner for storing packaging is evaluated by SCT test in machine cross direction and test liner for transport packaging is evaluated by burst strength. Relationship between calculated SCT values and semichemical pulp content in mixture recovered fibres prepared by technologies A, B, and BK including with addition of 10% of groundwood (AD10K and BD10K) is presented on Fig.5. SCT value increases in all technology alternatives with increasing semichemical pulp content in the paper furnish. Increase of semichemical pulp content from 40% to 50% increased SCT approximately by 5.5% when technologies A, B and BK were applied. This increase is same as in case of CMT_{30} data.

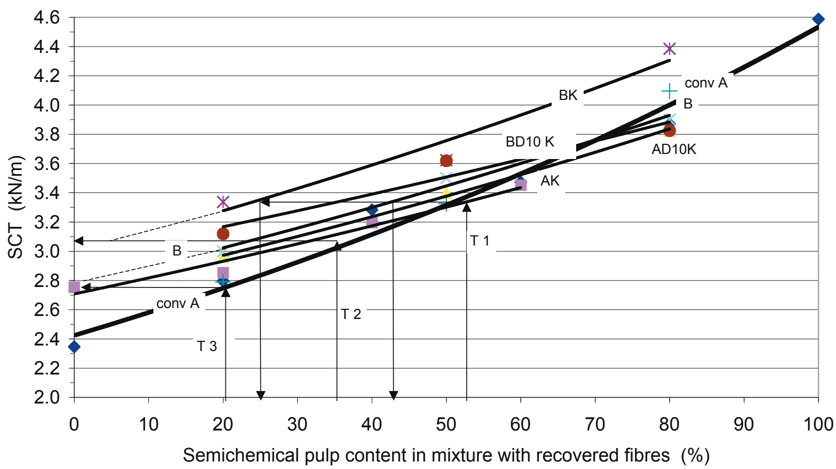

Fig. 5: Influence of technology on semichemical pulp input and SCT of paper

Influence of paper furnish treatment technology own SCT is analogous to CMT_{30} data. At a same semichemical pulp content in the furnish, e.g. 35% the increasing influence of treatment technologies on SCT can be expressed by the following sequence: A (3.05 kN/m) < AK (3.11 kN/m) < AD10K (3.17 kN/m) < B (3.23 kN/m) < BD10K (3.33 kN/m) < BK (3.52 kN/m). Numbers in brackets are SCT values of test sheets with 127 g/m^2 basis weight. Refining of recovered fibres (technology B) increased SCT approximately by 6%. Influence of the retention and drainage system was more expressed in combination with recovered fibres refining. SCT increased in this case by 15% (technology BK) when compared with technology A.

By application of an optimal technology, i.e. a combination of fibrillation refining of recovered fibres and of a nanoparticle retention and drainage system SCT increase was achieved, which enables reduction of semichemical pulp content in the test liner quality class T1 to T3 furnish as it is shown on Fig. 5 and summarised in Tab. 2.

Relationship between burst index and semichemical pulp content in the furnish with recovered fibres prepared by technology A, AK, B a BK with admixture 10% groundwood (AD10K and BD10K) is presented in Fig.6. Increase of semichemical pulp input from 20% to 80% resulted in burst index increase from 2.18 $kPa.m^2/g$ to 3.5 $kPa.m^2/g$. At a same e.g. 35% semichemical pulp input the increase influence of treatment technologies can be expressed by the following sequence: A (2.42 $kPam^2/g$) = AD10K< BD10K (2.55 $kPa.m^2/g$) < AK (2.6 $kPa.m^2/g$) < B (2.75 $kPa.m^2/g$) < BK (3.15 $kPa.m^2/g$). Numbers in brackets are burst index values of 127g/ m^2 test sheets. Refining of recovered fibres (technology B) increased of burst index by 14%. Influence of the retention and drainage system was significantly expressed in combination of recovered fibres refining resulting in burst index increase by 31% (technology BK) when compared with conventional technology A. Admixture of groundwood resulted in decrease of burst index.

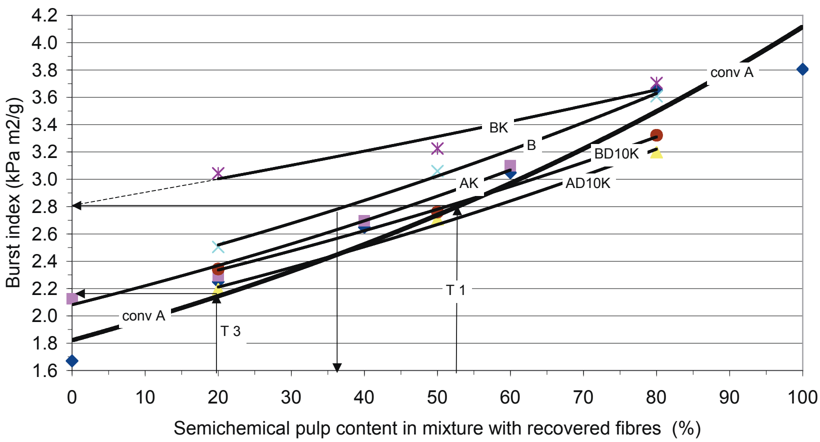

Fig. 6: Influence of technology on semichemical pulp input and burst index of paper

Treatment of recovered fibres by the optimal technology i. e. by combination of fibrillation refining with a nanoparticle retention and drainage system (technology BK) a significant increase of burst index was achieved enabling reduction of semichemical pulp input in production of quality class T1 to T3 test liners as illustrated on Fig. 6 and summarised in Tab. 2. In columns of modified technology B and BK the higher level of semichemical pulp input refers to the required SCT and the lower level refers to burst index of individual quality class test liners. In case of test liners used for production of storing packages the required SCT value is in cross direction, which represents about 75% on mean SCT value and the virgin fibres input corresponds to lower values shown in Tab.2.

Tab. 2: Input of semichemical pulp in test liners T1, T2 and T3 prepared by technologies A, B and BK

Test liner quality	Requirements			Conventional technology A	Modified technology B	Modified technology BK
	SCT (kN/m)	Burst index (kPa.m^2/g)	*Porosity Gurley (s)*			
T1	3.35	2.80		52	42 - 37	24 - 0
			Gurley (s)	*43*	*46*	*33*
T2	3.05	2.45		35	24 - 15	5 - 0
			Gurley (s)	*33*	*38*	*33*
T3	2.75	2.15		20	0	0
			Gurley (s)	*26*	*32*	*33*

Summarised results in Tab. 2 are confirming that application of optimal technology i.e. recovered fibres refining in combination with a nanoparticle retention and drainage system (technology BK) 20% to 52% reduction of semichemical pulp was achieved in test liner furnish of qualitative class T1 to T3. Refining of recovered fibres enables 10% to 20% reduction of semichemical pulp content in the furnish mainly in case of test liner T3 and T2.

CONCLUSIONS

1. High correlation was found between measured CMT_{30} and SCT values and values calculated from bending resistance, internal bond strength and porosity of commercial flutings based on NSSC and soda-AQ semichemical pulp.
2. These findings were used in determination of recovered fibres refining, nanoparticle retention and drainage system application and groundwood admixture influence on bonding potential of virgin and recovered fibres mixture.
3. A most significant increase of CMT_{30}, SCT and burst strength was achieved by application of a technology combining recovered fibres refining with a nanoparticle retention and drainage system. Technology without combination of these processes applying just refining of recovered fibres or just a nanoparticle retention and drainage system are not resulting in a significant improvement of fluting and test liner parameters.
4. A mild refining of recovered fibres does not increase significantly internal bond strength but activates the surface of fibres and makes it accessible to interfibre bonds by starch.
5. Addition of groundwood into a mixture of virgin and recovered fibres caused decrease of strength parameters as a consequence of low internal bond strength of groundwood.

6. Application of the optimal combined treatment technology in preparation of paper from virgin and recovered fibres increase of CMT_{30} by 7-20%, SCT by 6-21% and burst strength by 7-38% was achieved depending of semichemical pulp content (20-80%) in paper, while porosity of paper was preserved.
7. Laboratory experiments showed that by application of optimal combined treatment technology is possible in fluting manufacture to reduce the conventional 25-70% content of semichemical pulp by 20-38%
8. Application of combined treatment technology in test liner manufacture can improve test liner T3 quality with 20% semichemical pulp content to the level of quality class T2 with semichemical pulp content 5-0%.

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REFERENCES

1. Baker, C.F., 1995: Good practice for refining the types of fiber found in modern paper furnishes. Tappi J. 78 (2): 147-154
2. Leider, P. J., Rihs, J., 1977: Understanding the disk refiner. I. The hydraulic behavior. Tappi J. 60 (9): 98-102
3. Leider, P.J., Nissan, A.H., 1977: Understanding the disk refiner. II. The mechanical treatment of the fibers. Tappi J. 60 (10): 85-89
4. Lumiainen, J.J., 1997: Comparison of the mode of operations between conical and disc refiners. Paper Technology 38 (2): 53-61
5. Nahrath, G., 2004: Trends in der Herstellung von Wellpappe und Anforderungen an die Wellpappenrohpapiere. Wochnbl. Papierfabrikat. 132 (1-2): 18-25
6. Naujock, H.J., 2001: Neue Aspekte der Mahlungstheorie. Wochnbl. Papierfabrikat. 129 (8): 498-503
7. Ortner, G., 2004: Mahlungstechnologie und Rückstoffbehandlung. Wochnbl. Papierfabrikat. 131 (13): 806-814
8. Ortner, G., Hietanummi, J., 2004: Kurzfasermahlung-Eine neue Chance und Herausforderung. Wochnbl. Papierfabrikat. 131 (18): 1070-1079
9. Vullierme, I., Serra-Tosio, J.M., 2000: Étude de l´influence des propriétés mécaniques des papiers sur les résistances á la compression SCT et CMT. Optimisation de la qualité des PPO. Revue ATIP 54 (2): 40-48
10. Wultsch, F., Flucher, W., 1958: Der Escher-Wyss-Kleinrefiner als Standard-Prüfgerät für moderne Stoffaufbereitungsanlagen. Das Papier 12 (13/14): 334-342

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