REINFORCEMENT POTENTIAL OF BLEACHED SAWDUST KRAFT PULP IN DIFFERENT MECHANICAL PULP FURNISHES

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Bleached unrefined and refined sawdust kraft pulps were added to bleached Norway spruce thermomechanical (TMP) and pressurised groundwood (PWG) pulps in different proportions. Handsheets were prepared and tested for physical properties. In addition, economic calculations were done to estimate the production costs of different bleached pulps in Finland. It was found that the addition of unrefined and refined sawdust kraft pulp improved drainability of the mechanical pulps. Tear strength of PGW furnishes was increased when either unrefined or refined sawdust pulp was added. Tear strength of TMP furnishes was not influenced when different sawdust kraft pulps were added. Up to 30 % of unrefined sawdust kraft pulp could be added and no significant negative effect was observed in TMP and PGW furnishes. On the other hand, when refined sawdust kraft pulp was added into the mechanical pulp furnishes, a clear improvement in the tensile strength was observed. According to the economic calculation the production cost of bleached sawdust kraft pulp is almost as low as the production cost of bleached mechanical pulp. We suggest that economically viable sawdust kraft pulp can be used as a substituent for expensive long fibre reinforcement kraft pulp in the production of mechanical pulp based papers.

Keywords: Bleached sawdust kraft pulp; TMP; PGW; Economics

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INTRODUCTION

Wood-containing printing papers are mainly produced from mechanical pulps such as pressurised groundwood pulp (PGW) or thermomechanical pulp (TMP). These printing papers contain 25–100 % mechanical pulp, depending on the paper grade (Haarla 2000). Uncoated SC paper contains 55–65 % mechanical pulp, coated LWC paper contains 55–65 % mechanical pulp, and newsprint can totally be made of mechanical pulp (Sundholm 1999). Mechanical pulps give different papers bulk and opacity (Franzén and Jännäri 1989) but limited strength. Chemical reinforcement fibres are therefore added to mechanical pulp based papers in order to improve runability and the mechanical properties of the produced paper (Hiltunen et al. 2002). The softwood kraft pulp fibres reinforce mechanical pulps due to increased fibre length and the number of long fibres (Retulainen 1991; Retulainen 1992). For that reason reinforcement fibres should be long, flexible, and their coarseness should be low (Levlin 1991). Reinforcement fibres are refined in order to increase the bonding ability of fibres and improve the strength properties. Therefore reinforcement pulp is refined relatively little, not to cut fibres; thus reinforcement pulp contains long fibres and it is low in fines (Honkasalo 2004).

Reinforcement kraft pulp is usually expensive, and therefore its share in mechanical printing papers is kept as low as possible. One possibility to replace expensive long fibre chemical pulp is to use less expensive sawdust pulp as a reinforcement pulp. Sawdust kraft pulp has lower strength properties than conventional softwood kraft pulp. However, the short fibres in sawdust kraft pulp increase opacity, surface smoothness, absorption ability, dimensional stability, and printability. Also, sawdust kraft pulp improves formation and dewatering (Rantasuo 1976). The number of fibres per gram of kraft pulp for Scandinavian pine is 2.5 million (Levlin and Jousimaa 1988). Sawdust kraft pulp has considerably more fibres per gram of pulp. This may compensate for the lower strength of sawdust kraft pulp.

The aim of this work was to add bleached unrefined and refined sawdust kraft pulp into bleached mechanical pulps in order to examine whether sawdust pulp can reinforce mechanical pulp based papers. Also, economic calculations were done to estimate the cost of bleached long fibre reinforcement kraft pulp, bleached mechanical pulp, and bleached sawdust kraft pulp.

EXPERIMENTAL

Unbleached sawdust kraft pulp was collected at a Finnish pulp mill from a thickener after pulp washing and screening, i.e. pulp that goes to the paper machine. Peroxide bleached Norway spruce thermomechanical pulp (TMP) and pressurised groundwood pulp (PGW) were collected at a Finnish paper mill. Unbleached sawdust pulp was bleached using a D_0-E_P-D_1-E_P sequence to a brightness of 83.5%. Bleached sawdust pulp was refined with Valley beater according to ISO 5264-1 to °SR 33, and the drainability of pulp samples was determined using the Schopper-Riegler method according to ISO 5267-1. Approximately 60 g/m^2 handsheets were made according to SCAN 26:76. No draining time was applied after the sheet was formed on the wire screen. Sheets containing mechanical pulps were made with white water circulation. The pressing was done according to ISO 5269-1, and the handsheets were conditioned according to ISO 187. Apparent density was determined according to ISO 534, tensile strength according to ISO 1924-2, and tear strength according to ISO 1974. Brightness, opacity, and light-scattering coefficient were determined according to ISO 2470 and ISO 2471. Air resistance was determined according to ISO 5270. The pulp samples were also analysed with a Kajaani FiberLab Analyzer. The measuring speed was approximately 90 fibres per second, and the analysis consistency of the sample was 0.015–0.025 % for pulps with longer fibres (TMP) pulp and 0.005–0.01 % for pulps with shorter fibres (PGW and sawdust pulps) (Mörseburg et al. 1999).

Unrefined and refined bleached sawdust pulps were blended with TMP and PGW pulps according to Table 1.

Table 1. Blends of Different Pulp Furnishes. The freeness of refined sawdust pulp was 33 °SR.

Sawdust pulp, unrefined or refined (%, w/w)	TMP (%, w/w)
0	100
5	95
15	85
30	70
45	55
100	0
Sawdust pulp, unrefined or refined (%, w/w)	PGW (%, w/w)
0	100
5	95
15	85
30	70
45	55
100	0

The production costs of bleached softwood kraft pulp, bleached mechanical pulp, and bleached sawdust kraft pulp were estimated using the price of wood because it is the biggest cost factor. The wood consumption to produce different bleached pulps can be calculated according to Varhimo et al. (2003),

$$W_{\mathrm{cons}} = \frac{0.9}{(1-b)\cdot \rho \cdot Y} \tag{1}$$

where, W_{cons} = wood consumption, solid m^3/admt (solid cubic metre per air-dry metric tonne of pulp), b = bark content, fractional, ρ = o.d. wood density, t/m^3, and Y = yield of o.d. bleach pulp, fractional.

The following data were applied when calculating the wood consumption of the different pulps. The bark content of Norway spruce wood is 9.3 % (Björklund 2004). The wood density is 400 kg/m^3 and dry content 50 % (Duchesne et al. 1997). The yield of bleached reinforcement kraft pulp is 45.5 % (Kovasin and Tikka 1993), the yield of bleached TMP is about 92 % (Holmbom et al. 2005), and the yield of bleached sawdust kraft pulp is ca 39.5 % (Korpinen and Fardim 2008). The bark content in sawdust is ignored because it cannot be removed before the kraft pulping. The wood consumption is hence 5.45 solid m^3/admt for bleached reinforcement kraft pulp (RIF), 2.70 solid m^3/admt for bleached mechanical pulp, and 5.70 solid m^3/admt for bleached sawdust kraft pulp. Sawdust is usually delivered as a bulk product to the pulp mills. One loose m^3 corresponds to about 300 kg at a typical moisture content (Alakangas 2005); hence the amount of sawdust needed for 5.92 solid m^3/admt wood consumption is 15.2 loose m^3/admt.

RESULTS AND DISCUSSION

Properties of the different pulp fibres are listed in Table 2. TMP fibres were longer than PGW fibres. Also, both unrefined and refined sawdust kraft pulp fibres were longer than PGW fibres. The fibre width of TMP and sawdust kraft pulps was higher than that of PGW. TMP fibre walls were thicker than the rest of the studied fibres. PGW and sawdust kraft pulps contained considerably more fibres per unit weight than TMP. Also their fines content was higher than TMP.

Table 2. Properties of TMP, PGW, Bleached Sawdust Kraft Pulp and Refined Sawdust Kraft Pulp Fibres

	TMP	PGW	BSDKP	BSDKP R (°SR 33)
Fibre length (mm)	**1.67** ± 0.04	**0.84** ± 0.03	**1.17** ± 0.03	**1.00** ± 0.04
Fibre width (µm)	**28.56** ± 0.42	**22.59** ± 0.51	**28.42** ± 0.28	**26.72** ± 0.22
Fibre wall (µm)	**8.05** ± 0.22	**6.58** ± 0.12	**6.96** ± 0.28	**6.85** ± 0.14
Curl (%)	**15.99** ± 0.50	**15.03** ± 0.47	**9.06** ± 0.35	**8.38** ± 0.21
Coarseness (mg/m)	**0.27** ± 0.03	**0.17** ± 0.01	**0.17** ± 0.00	**0.15** ± 0.00
10^6 fibres/g	**4.35** ± 0.39	**14.63** ± 0.98	**11.97** ± 0.10	**17.21** ± 0.26
Fines (%)	**20.32** ± 0.75	**34.81** ± 1.47	**39.62** ± 1.13	**45.30** ± 0.82

Mean length-weighted fibre length. BSDKP: bleached sawdust kraft pulp, BSDKP R: bleached and refined (°SR 33) sawdust kraft pulp.

The drainage resistance of PGW pulp was higher than that of TMP pulp, because PGW pulp contains more fines that retain water, as can be seen in Fig. 1. The drainability of the mechanical pulp furnishes increased with the addition of both unrefined and refined sawdust pulp. An interesting feature was observed when adding 5–30 % unrefined sawdust kraft pulp into the mechanical pulps. The drainability was lower compared with adding refined sawdust pulp, even if the fines content of the unrefined sawdust pulp was lower than that of refined sawdust pulp. However, due to a low number of samples and tests, no strong indication can be made that there was a higher °SR for unrefined pulps.

The bulk of TMP and PGW based papers can be seen in Fig. 2. The bulk of TMP and PGW pulp furnishes was high and remained more or less constant regardless of the amount of unrefined sawdust pulp added into the pulp furnishes. This is attributed to the high bulk of unrefined sawdust pulp. In contrast to unrefined sawdust pulp, the refined sawdust pulp had a lower bulk, and therefore the increased amount of refined pulp in mechanical pulps decreased the bulk. However, the bulk of the different mechanical pulp furnishes did not decrease clearly until 30 % of refined sawdust pulp was added.

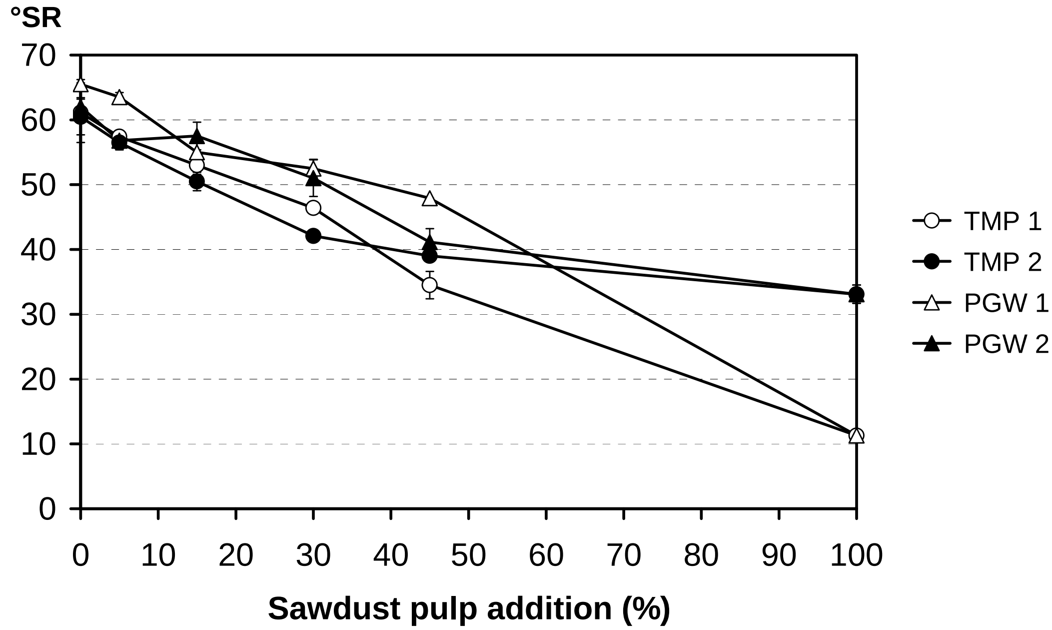

Fig. 1. Drainability of the different pulp furnishes. TMP 1: Bleached thermomechanical pulp blended with bleached, unrefined sawdust kraft pulp, TMP 2: Bleached thermomechanical pulp blended with bleached, refined sawdust kraft pulp, PGW 1: Bleached pressurised groundwood pulp blended with bleached, unrefined sawdust kraft pulp, PGW 2: Bleached pressurised groundwood pulp blended with bleached, refined sawdust kraft. 0 % sawdust addition: pulp furnish consists only of TMP or PGW. 100 % sawdust addition: pulp furnish consists only of unrefined or refined sawdust pulp.

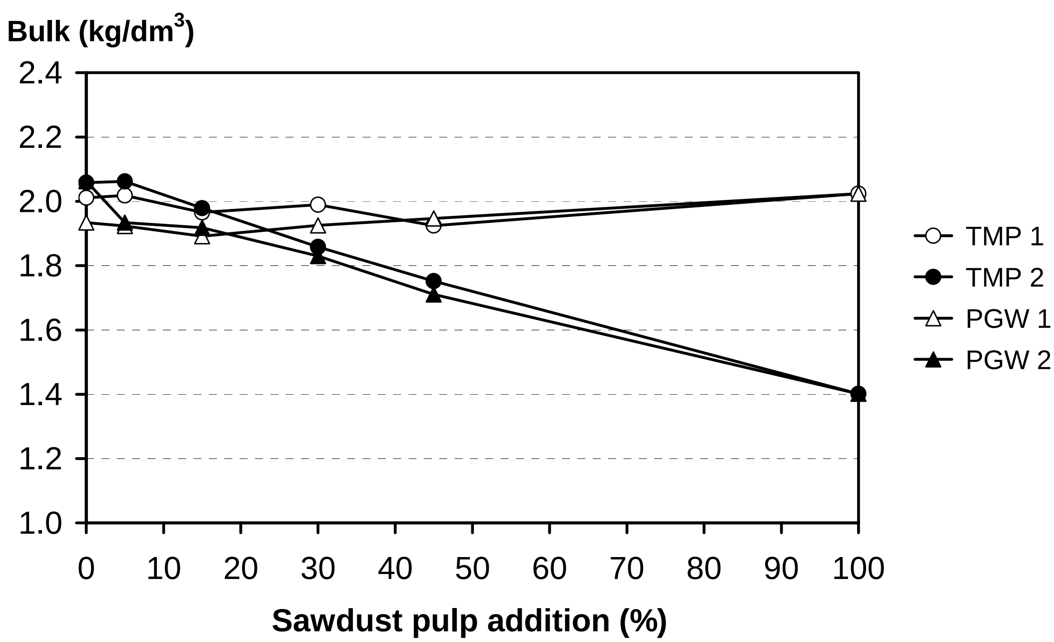

Fig. 2. Bulk of the different pulp furnishes. The addition of unrefined sawdust pulp did not affect the bulk of mechanical pulps.

TMP pulp had higher tear strength than PGW pulp. It is proposed that this is because TMP contained longer fibres, see Fig. 3. Tear index depends on the fibre length and its strength. It has been shown that tear strength is increased with increasing fibre length (Mohlin 1989; Seth 1990a; Retulainen 1996). Tear index of TMP remained almost unchanged when unrefined sawdust pulp was added, because tear strength of unrefined sawdust pulp was at the same level as TMP. Addition of refined sawdust pulp decreased the tear strength of TMP pulp furnishes only slightly.

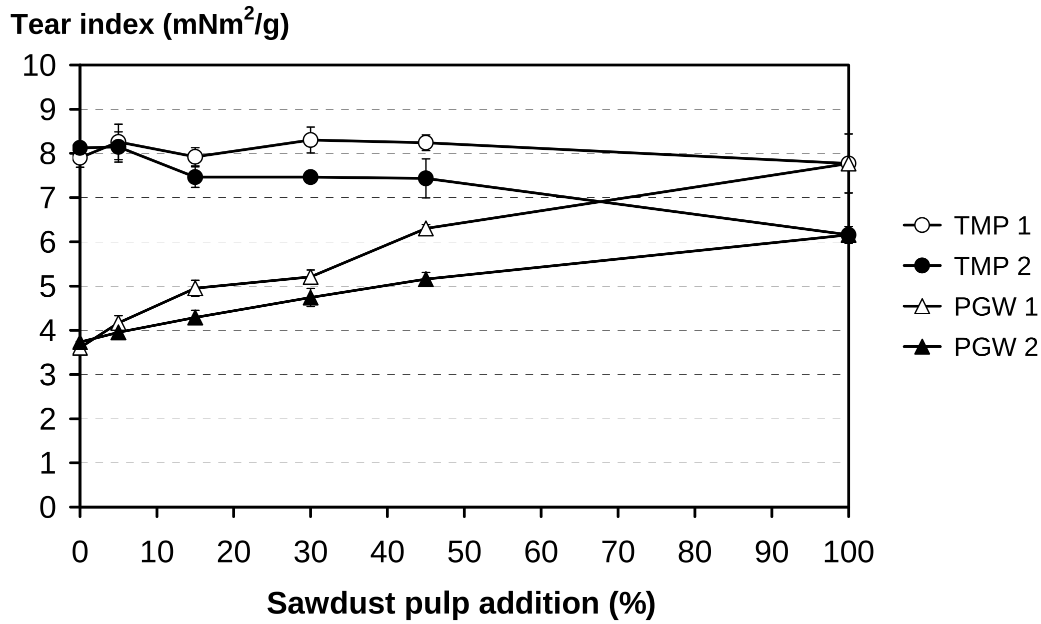

Fig. 3. Tear index of the different pulp furnishes. The addition of unrefined and refined sawdust pulp could improve the tear index of PGW.

Tear strength of PGW pulp furnishes increased with increased addition of both unrefined and refined sawdust pulp. Unrefined sawdust pulp fibres were longer than refined sawdust pulp fibres. Also, the coarseness of unrefined sawdust pulp was higher. Coarser fibres improve the tear strength (Seth and Page 1988; Yu 2001). Therefore the addition of unrefined sawdust pulp into the PGW pulp furnishes showed higher increase in tear strength.

There were no significant differences in tensile strength between the TMP and PGW pulps, as reported earlier (Lindholm 1981). The addition of unrefined sawdust pulp into the mechanical pulp furnishes did not decrease the tensile strength, although the tensile strength of unrefined sawdust pulp was lower than that of TMP and PGW, which is illustrated in Fig. 4. In fact, the tensile strength of the mechanical pulp furnishes increased slightly when 5–15 % unrefined sawdust pulp was added.

Tensile strength of the mechanical pulp furnishes increased with increasing amount of refined sawdust pulp, even though the fibres in the sawdust pulp were relatively short compared to conventional softwood reinforcement pulp fibres. Refining of the sawdust pulp fibres improved the tensile properties. During refining, external and internal fibrillation occurs, the sawdust pulp fibres collapse, are cut, and fines are generated (Page 1989; Paavilainen 1993). Because of that, sawdust pulp fibres became more flexible, which made the formation of fibre-fibre bonds easier. Also, due to increased fines content of the sawdust pulp the tensile strength was increased (Hartman 1985; Page 1985).

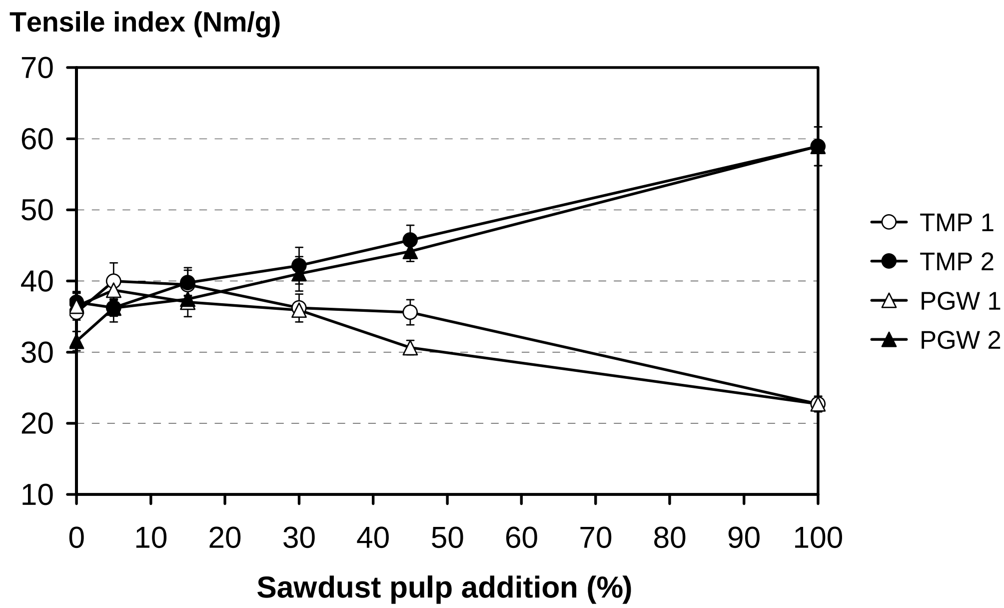

Fig. 4. Tensile index of the different pulp furnishes. The addition of refined sawdust pulp was positive to tensile index of TMP and PGW handsheets.

The addition of unrefined sawdust pulp into the mechanical pulp furnishes decreased the air resistance, indicating an increased porosity (Karlsson 2007). On the other hand, the air resistance was remained relatively constant when refined sawdust pulp was added into the mechanical pulp furnishes (see Fig. 5). Refined sawdust pulp fibres had lower coarseness than unrefined sawdust pulp fibres. Fibres with lower coarseness produce denser (lower bulk) and better bonded sheets which will show higher air resistance. The addition of refined sawdust pulp fibres decreased the bulk, which led to increased air resistance (Seth 1990a; Seth 1990b).

Opacity of the mechanical pulp furnishes decreased similarly, regardless of addition of unrefined or refined sawdust pulp, as seen in Fig. 6. In addition, the decrease in opacity was reasonably low compared with opacity of the both unrefined and refined sawdust pulps.

Light scattering of the mechanical pulp furnishes was high because of the mechanical pulp fines, see Fig. 7 (Nieminen 1995; Tuovinen and Liimatainen 1994; Stationwala 1995; Forset 1997; Retulainen 1997; Kure 1999). High specific surface area (SSA) also increases the light scattering coefficient. SSA can be increased with a high amount of fines or high degree of fibrillation (Reme 2000). The fines content and SSA of sawdust pulps were high. Nevertheless, the addition of unrefined and refined sawdust pulps decreased the light scattering coefficient. Free surfaces of the fibres scatter light, i.e. lower the light scattering, the higher the bonding. Sawdust pulp fines impaired light scattering coefficient because the chemical pulp fines has better bonding ability than mechanical pulp fines (Retulainen et al. 1993).

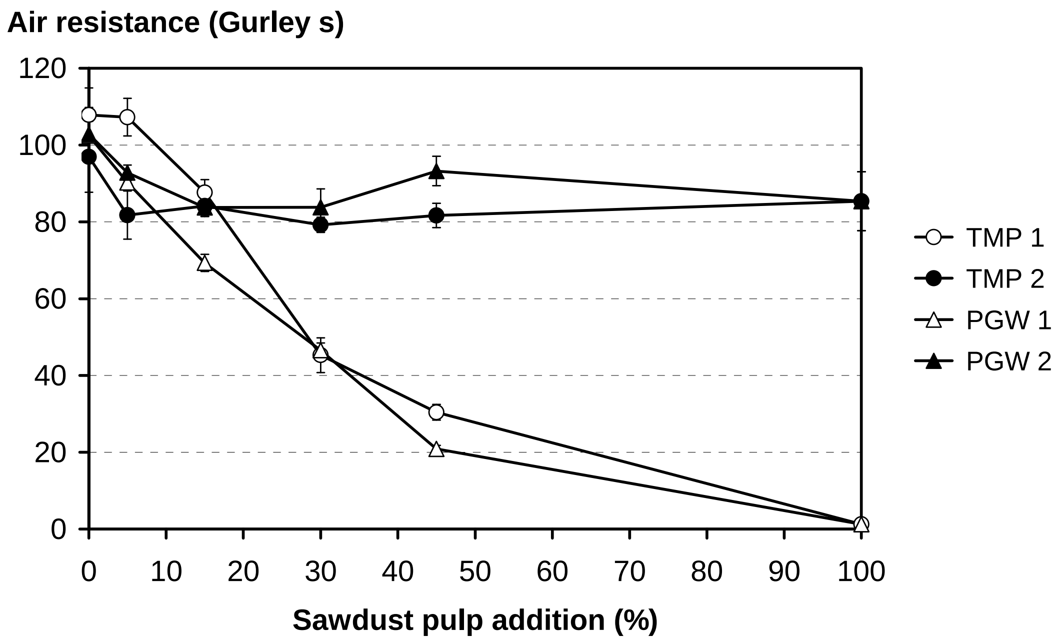

Fig. 5. Air resistance of the different pulp furnishes

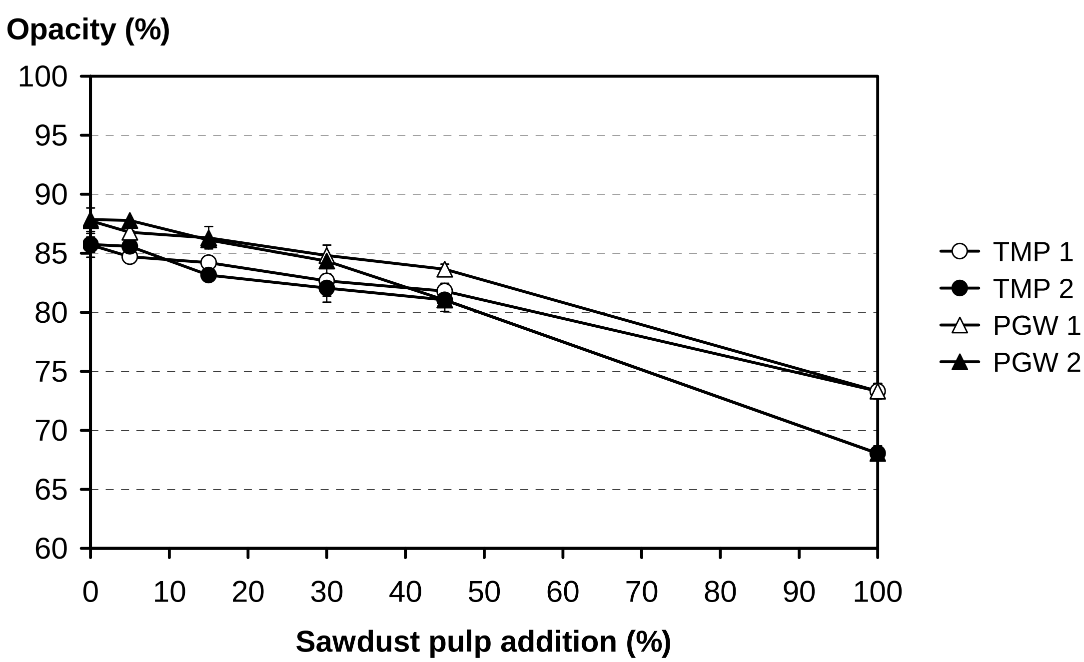

Fig. 6. Opacity of the different pulp furnishes

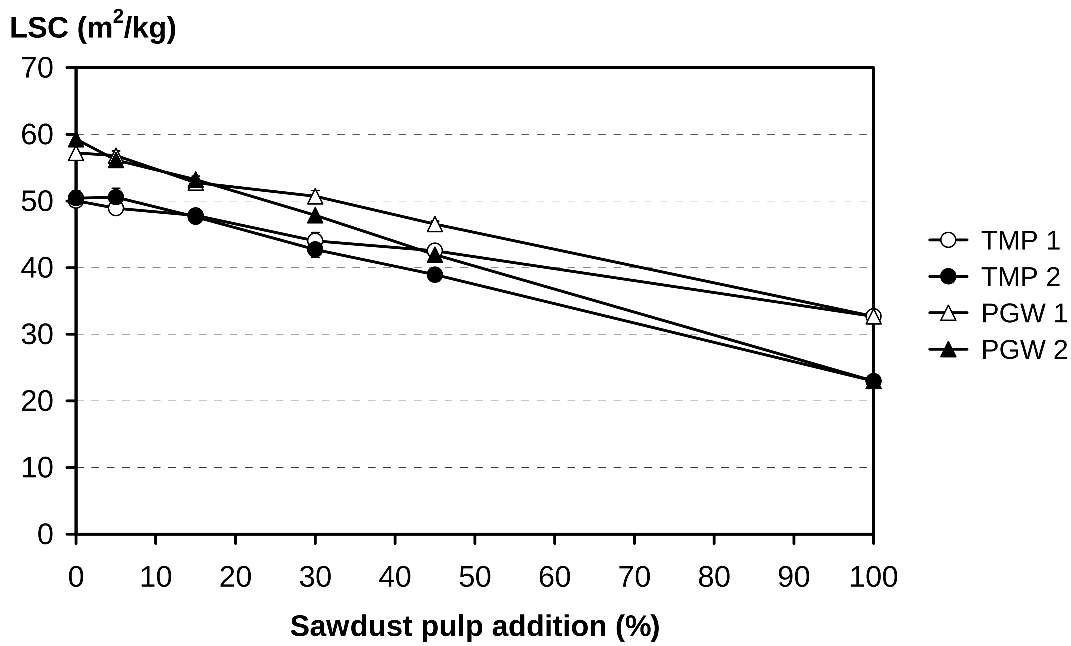

Fig. 7. Light scattering coefficient of the different pulp furnishes

The brightness of the mechanical pulp furnishes remained more or less constant when either unrefined or refined sawdust pulp was added into the different furnishes, as can be seen in Fig. 8.

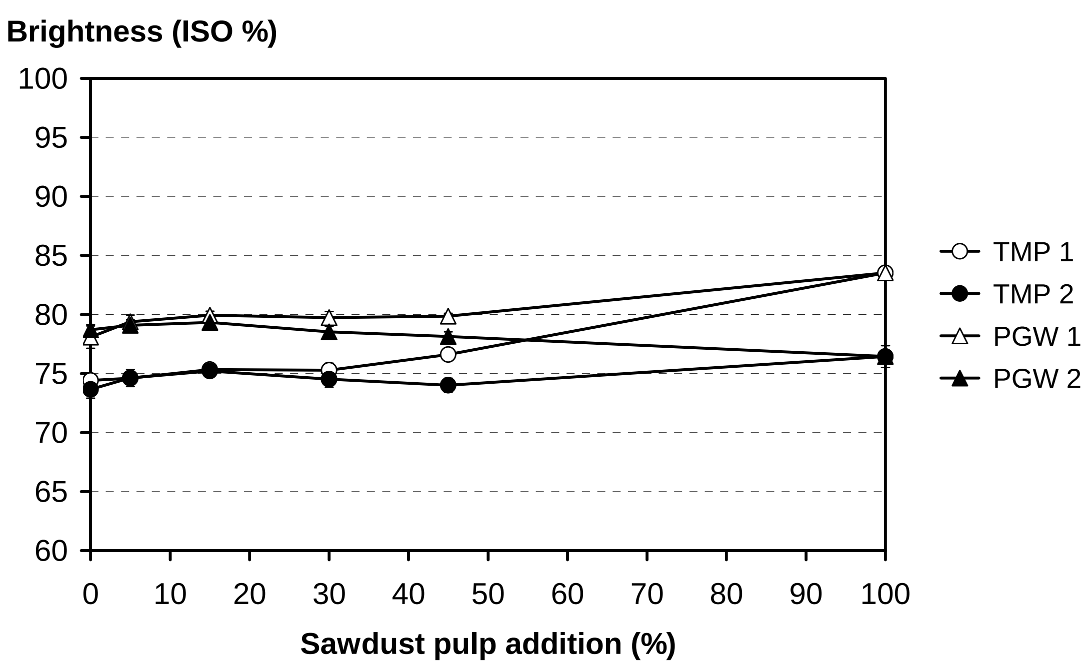

Fig. 8. Brightness of the different pulp furnishes

The main cost component of manufacturing softwood reinforcement kraft pulp, excluding capitals costs, is the cost of wood. The cost of wood, excluding capital costs, is around 48.6 %, as seen in Table 3 (Diesen 1998). Other costs are chemicals, energy, operating materials, services, maintenance materials, personnel and administration, and others. The price of Norway spruce roundwood is approximately 34 €/solid m^3 (Metla 2009), and the wood consumption of RIF pulp is 5.45 solid m^3/admt. The cost of roundwood is then around 185.4 €/admt, and the total production cost of bleached RIF pulp excluding capital costs will be approximately 381.5 €/admt, which is illustrated in Table 3. The calculated cost is relatively close to a value reported earlier (Pineault 2006).

Table 3. The Cost Factor Distribution of Softwood Reinforcement Kraft Pulp

Cost factor	Incl. capital costs, %	Excl. capital costs, %	€/admt
Wood	31	48.6	185.4
Chemicals	7.9	12.4	47.2
Energy	0.7	1.1	4.2
Operating materials, services	10.7	16.8	64.0
Maintenance materials	5.2	8.2	31.1
Personnel and administration	3.3	5.2	19.7
Others	5	7.8	29.9
Capital costs	36.2		
Total	100	100	381.5

The calculated cost factors for mechanical pulp are presented in Table 4. Also in this case, the main cost component is the cost of wood. Other cost factors are chemicals, packing materials, energy, operating materials, maintenance materials, personnel and administration, and others (Diesen 1998). The price of wood is approximately 34 €/solid m^3 (Metla 2009), and the wood consumption is 2.70 solid m^3/admt. The total production cost of bleached mechanical pulp is 280.4 €/admt, which is close to reported values of 250–280 €/t (Honkasalo 2004).

Table 4. The Cost Factor Distribution of Newsprint

Cost factor	Incl. capital costs, %	Excl. capital costs, %	€/admt
Raw material (wood)	23.8	32.7	87.6
Chemicals	6.7	9.2	24.7
Packing materials	2.0	2.7	7.4
Energy	13.2	18.1	48.6
Operating materials	3.6	4.9	13.3
Maintenance materials	5.5	7.6	20.3
Personnel and administration	13.7	18.8	50.4
Others	4.3	5.9	15.8
Capital costs	27.2		
Total	100	100	280.4

Finally, the cost factors for bleached sawdust kraft pulp are calculated, and they can be seen in Table 5. The price for sawdust is 6.1 €/loose m^3 (Ylitalo 2006), and the wood consumption is 15.2 loose m^3/admt. Therefore, the cost wood in the production of bleached sawdust kraft pulp is 92.7 €/admt, as seen in Table 5. The rest of the production costs are taken from Table 3, even though their value might be overestimated.

Table 5. The Cost Factor Distribution of Sawdust Kraft Pulp

Cost factor	Excl. capital costs, €/admt
Wood	92.7
Chemicals	47.2
Energy	4.2
Operating materials, services	64.0
Maintenance materials	31.1
Personnel and administration	19.7
Others	29.9
Capital costs	
Total	288.8

According to Tables 3 and 5, bleached sawdust kraft pulp is 24.3 % cheaper than bleached softwood reinforcement kraft pulp. In addition, the production cost of bleached sawdust kraft pulp excluding capital cost is almost as the same as the production cost of bleached mechanical pulp.

CONCLUSIONS

1. The drainability of TMP and PGW was improved when bleached unrefined and refined sawdust kraft pulp was added into the different pulp furnishes.
2. Bulk of the different mechanical pulps was not affected when unrefined sawdust pulp was mixed into the different furnishes. Also, the bulk of the mechanical pulp furnishes was only slightly affected by adding 30 % of refined sawdust kraft pulp.
3. Tear strength of TMP was nearly unchanged regardless of the addition of unrefined or refined sawdust pulp. Tear strength of PGW was improved when either unrefined or refined sawdust kraft pulp was mixed into the paper.
4. Tensile strength of TMP and PGW pulp furnishes was not impaired when 30% of unrefined sawdust pulp was blended in. On the other hand, when refined sawdust pulp was added to the mechanical pulp furnishes, the tensile strength was improved.
5. Opacity of TMP and PGW pulps was slightly decreased, and it was decreased similarly, when unrefined or refined sawdust pulp was added.
6. Air resistance of the mechanical pulps was not influenced by addition of refined sawdust pulp, but it decreased rapidly when unrefined sawdust pulp was added.
7. Light scattering of the TMP and PGW pulps was decreased slightly with the addition of both unrefined and refined sawdust kraft pulp. Furthermore, the brightness was

nearly constant when both sawdust kraft pulps were added into the mechanical pulp furnishes.

8. The production cost of bleached reinforcement kraft pulp was much higher than the production cost of bleached mechanical pulp and bleached sawdust kraft pulp in Finland. Moreover, the production cost of bleached sawdust kraft pulp is almost equal to the production cost of mechanical pulp.
9. We suggest that bleached sawdust kraft pulp can be used to replace softwood kraft pulp in mechanical pulp based papers, because it can improve certain physical properties. We also suggest that it is economically more viable to use bleached sawdust kraft pulp instead of softwood kraft pulp, especially when the reinforcement strength requirement is moderate.

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