Fibre characteristics of papers used in European corrugated packaging industry

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ABSTRACT

A number of representative papers used in corrugated packaging industry were investigated to analyze their fibre characteristics. These papers were selected to cover different qualities of linerboard and corrugating medium available in European packaging industry. The papers tested were provided by fourteen paper suppliers from the global market and refer to kraft-liner (grammage 125-225 g/m²), test-liner (grammage 100-170 g/m²), brown bicolor (grammage 105-160 g/m²), white recycled liner (grammage 140-175 g/m²), semi-chemical fluting (grammage 127-150 g/m²), recycled fluting (grammage 95-160 g/m²) and schrenz (grammage 112 g/m²). For each of the papers, microslides were prepared with fibres and were observed under light microscope. Qualitative and quantitative analysis included fibre counts, weight proportions, pulping processes and type of fibres and was based on morphological characteristics of fibres and on colours developed by the Herzberg stain according to ISO 9184-1,3: 1990. In all cases the papers were consisted mainly from mixtures of chemical, semi-chemical and chemi-mechanical pulps in various weight proportions. The morphological characteristics of softwood tracheids showed that they belong to Strobus-Sylvestris pine group, Halepensis-Ponderosa-Taeda pine group, Kesiya pine group, *Picea* or *Larix, Abies* and *Pseudotsuga*. Observations on vessel member morphology led to the genera *Eucalyptus, Betula, Populus, Fagus, Tilia* and gums. Nonwood cell types (grass, bast, leaf and fruit fibres, parenchymatous and epidermal cells) were observed in low proportions. The results showed that the raw materials used for the production of papers were very variable due to recycling.

INTRODUCTION

Nowadays, there is a great availability of grade papers used in corrugating packaging manufacture. Forest-based materials, traditionally the main source of paper, are gradually being reduced in fabrication process of these papers while recycled pulp favoured by relevant legislation (European Commission 1994, 2004, 2005), is becoming an increasingly important source material. As a result, corrugating packaging industry is facing the challenge to combine raw materials with dissimilar characteristics and to produce goods with homogenous properties.

Effective utilization of papers in production of packages depends on their reliable and detailed characterization. Recent studies on a variety of papers available in the market for the production of corrugated board in Spain have shown that, besides physical-mechanical testing, fibre analysis techniques may be also used to analyze both their time-varying structure and quality (Adamopoulos 2006a, Adamopoulos 2006b, Adamopoulos and Oliver 2006a, Adamopoulos and Oliver 2006b). The ongoing European project MODELPACK (COLL-CT-2006-030299) also addresses this technological problem of the European packaging sector, the diversity of raw materials with increasing proportions of recycled fibres and the difficulty of predicting the properties of final fibre products.
The objective of present work in the framework of MODELPACK project was to gather information on fibre characteristics of grade papers most commonly used by packaging companies throughout Europe, with a view to constructing a database necessary for the development of a quality prediction system.

MATERIALS AND METHODS

Material

Twenty three (23) representative papers used in corrugated packaging industry were used to analyze their fibre characteristics. These papers were selected to cover different qualities of linerboard and corrugating medium available in European market for the production of corrugated board. The papers were provided by five European corrugated board companies and came from fourteen paper suppliers from the global market (13 European and 1 from USA). The characteristics of the papers are shown in Table 1.

Table 1. Paper characteristics

Paper ID	Grammage (g/m^2)	Classification*
Linerboards		
KL	125, 140, 170, 170, 225	**KL: brown kraft-liner** (predominantly made from primary kraft pulp)
TL	100, 115, 170	**TL: test-liner** (predominantly recycled fibre based with guaranteed property requirements)
BB	105, 110, 110, 160	**BB: brown bicolor** (a predominantly recycled fibre based paper, with burst index > 1.6)
WRL	140, 175	**WRL: white recycled liner** (predominantly recycled fibre based with guaranteed brightness, roughness and burst index)
Corrugating medium		
SCF	127, 150, 150	**SCF: semi-chemical fluting** (predominantly made from semi chemical primary fibres pulp)
RF	95, 105, 110, 125, 160	**RF: recycled fluting** (predominantly recycled fibre based with guaranteed property requirements)
SHR	112	**SHR: schrenz** (predominantly recycled fibre based fluting without guaranteed property requirements)

** According to ECO and GROUPEMENT Ondulé (2003) classification code*

Maceration and microslide preparation

For each of the papers small pieces were dispersed in water by boiling and shaking. Microscope slides were prepared with fibres according to ISO 9184-1: 1990.

Identification of pulping processes and fibres

The qualitative and quantitative determination of the fibre components of papers was carried out by using the Herzberg staining test method (ISO 9184-3: 1990). Staining of the fibres was performed by adding 2 or 3 drops of Herzberg stain to the fibre field on each slide and covered with a cover glass in such a way as to avoid air bubbles. The slides were allowed to stand 1-2 minutes and then bringing the long edges of the slides into contact with a blotter drained off the surplus stain.

The stained microslides were examined under a Nikon 50i light microscope equipped with a digital camera and a cross-hair eyepiece. The identification of pulping processes was based on the colours developed by the Herzberg stain as presented in Table 2. The fibres were classed into softwood, hardwood and nonwood fibres categories according to their morphology.

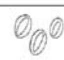
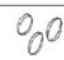
Table 2. Colour chart for Herzberg stain used for the identification of pulping processes of fibers in paper, board and pulps (taken from ISO 9184-3: 1990)[1]

Type of pulp	Colour
Chemical pulp	Blue, bluish-violet[1]
Mechanical pulp	Yellow
Rag pulp	Wine-red
Semi-chemical and chemi-mechanical pulp	Dull blue, dull yellow, mottled blue and yellow

[1] raw softwood kraft pulp at a yield of about 60% shows a dark yellow color

The identification of softwood groups and genera was performed mainly on the basis of cross-field pitting between different cells (pits in the crossings of longitudinal tracheids and the ray cells) according to classification proposed by Ilvessalo-Pfäffli (1995) (see Table 3).

Table 3. Identification of papermaking softwoods (Ilvessalo-Pfäffli 1995)

No	Softwood group/ Genera	Cross-field pits	
1	**Strobus group:** *Pinus strobus, P. monticola, P. lambertiana* **Sylvestris group:** *Pinus sylvestris, P. resinosa*	Window-like	
2	**Halepensis group:** *Pinus halepensis* **Ponderosa group:** *Pinus ponderosa, P. contorta, P. patula, P. radiata,P. pinaster* **Taeda group:** Southern pines (*Pinus taeda, P. echinata, P. elliottii, P. palustris, P. rigida*), *P. caribaea, P. banksiana*	Pinoid	
3	**Kesiya group:** *Pinus kesiya, P. merkusii, P. densiflora, P. nigra*	Window-like and pinoid	
4	*Picea, Larix* and *Pseudotsuga*	Piceoid (spiral thickenings only in *Pseudotsuga*)	
5	*Tsuga and Chamaecyparis*	Cupressoid	
6	*Abies, Cryptomeria, Thuja, Taxodium, Sequoia*	Taxodioid	

Identification of hardwood species or genera was based on the features of vessels elements (size and shape, type of perforations, presence of spiral thickenings, type of intervessel pitting, size, shape and arrangement of pits to ray parenchyma) (see Table 4).

Regarding to nonwood fibres, identified components were grouped to grasses, bast fibres, leaf fibres and fruit fibres (Table 5). This classification was based on the presence of varying type of fibres (width, length, shape of fibre ends) and cells other than fibres such as parenchyma, epidermal, vessel elements and rings from annular vessels.

Table 4. Identification of papermaking hardwoods (Ilvessalo-Pfäffli 1995)

No	Genera / Species	Anatomical features of vessel elements	
1	*Alnus, Betula, Nyssa sylvatica, Liquidambar styraciflua, Liriodendron tulipifera, Magnolia grandiflora*	Scalaliform perforations in all vessels	
2	*Acer, Tilia, Carpinus, Magnolia grandiflora*	Spiral thickenings in all vessels	
3	Temperate hardwoods: *Alnus, Betula, Fraxinus* Tropical hardwoods: *Acacia, Albizzia, Anthocephalus*	All pits on vessels are small to very small	
4	*Fraxinus, Ulmus, Carya, Castanea, Quercus*	Large and wide vessels (ring-porosity)	
5	Tropical hardwoods: *Gmelina, Acacia, Albizzia, Anthocephalus, Musanga, Shorea* Sub-tropical hardwoods: *Eucalyptus*	Drum- to barrel-shaped vessels, profusely pitted	
6	*Populus, Salix*	Fairly large vessels with simple perforations and oval to oval-angular pits to ray parenchyma	
7	*Fagus*	Fairly large vessels with simple perforations and scattered pitting	

No	Nonwood fibres group/ Common name	Anatomical features of cell types
1	**Grasses, papyrus and palms :** wheat, corn, sugar cane, common reed, bamboo, sabai, rice, albartine, esparto, papyrus, oil palm, raphia	Fibres : length and width (in general narrow, thick-walled with blunt or pointed ends and inconspicuous pits) Vessel elements : size Parencyma cells : size, shape, abudance Cells of epidermis: size and shape of long cells, type of silica bodies, occurance and shape of papillae, type of hairs
2	**Bast fibres :** flax, hemp, sunn, kenaf, jute, ramie, paper-mulberry, gambi, mitsumata	Fibres : general shape, surface markings, shape of lumen, shapes of fibre ends, irregularities in fibre walls, dimensions (in general flexible with prominent surface markings on the walls) Associated cells: short pitted fibres with pointed ends, pitted vessel elements, parenchyma cells, epidermis, hairs
3	**Leaf fibres :** abaca. sisal	Fibres : stiff and fairly smooth (finer and more pointed in abaca) Associated cells : rectangular epidermal cells with typical stomata (abaca), long narrow annular-spiral-netlike vessel elements and separated spirals (sisal)
4	**Fruit fibres :** cotton, ceiba	Fibres : ribbon-like, twisted (cotton), structureless, tubelike with air bubles enclosed in the lumen (ceiba)

Table 5. Identification of papermaking nonwood fibres (Ilvessalo-Pfäffli 1995)

Counting of stained fibres on the microslides was carried out systematically at a magnification of 80X according to ISO 9184-1: 1990. Fibre fragments less than 0.1 mm were ignored as well as parenchyma cells and ray tracheids. Larger fragments of the same fibre type were counted separately as fractions (1/2, 2/3 of fibre length), in order to

Paper grade		Fibre count						Proportion (%)	
		Chemical pulp			Semi-chemical and chemi-mechanical pulp			Chemical pulp	Semi-chemical and chemi-mechanical pulp
		SW	HW	NW	SW	HW	NW		
Linerboards									
KL	125	132	222	33	20	131	23	69	31
KL	140	269	93	12	48	158	2	64	36
KL	170	179	158	3	138	68	10	61	39
KL	170	205	140	-	113	99	24	59	41
KL	225	212	163	-	76	82	23	67	33
TL	100	157	108	14	21	284	7	47	53
TL	115	77	274	12	76	104	31	63	37
TL	170	94	190	2	92	176	6	51	49
BB	105	15	243	16	100	163	18	49	51
BB	110	98	262	14	70	121	31	63	37
BB	110	55	300	12	59	151	53	58	42
BB	160	69	286	-	41	146	84	57	43
WRL	140	34	486	1	66	87	3	77	23
WRL	145	29	341	-	67	141	24	61	39
Corrugating medium									
SCF	127	30	232	8	155	221	12	41	59
SCF	150	30	76	6	134	282	60	19	81
SCF	150	28	57	4	157	317	34	15	85
RF	95	49	418	-	76	109	91	63	37
RF	105	137	249	-	75	182	32	57	43
RF	110	58	306	-	20	167	53	60	40
RF	125	133	173	19	73	98	11	64	36
RF	160	62	261	1	50	143	69	56	44
SHR	112	35	322	8	34	174	14	62	38

SW: softwood, HW: hardwoods, NW: non-wood

be converted thereafter into whole fibres. Fibres that appeared to have been shortened only little were counted as whole fibres.

RESULTS

The results are shown in Tables 6-9 and Figure 1.

Table 6 shows the fibre counts per type of pulp (chemical,

Fibre category	Weight factor
Chemical pulp	
Softwood tracheids	1.00[a]
Hardwood fibres	
With gums (sweet gum, black tupelo, tulip poplar) in the pulp mix	0.58[b]
Without gums (sweet gum, black tupelo, tulip poplar) in the pulp mix	0.48[c]
Non-wood fibres	
With cotton linters in the pulp mix	0.69[d]
Without cotton linters in the pulp mix	0.61[e]
Semi-chemical and chemi-mechanical pulp	
Softwood tracheids	1.70[f]
Hardwood fibres	
With gums (sweet gum, black tupelo, tulip poplar) in the pulp mix	1.10[g]
Without gums (sweet gum, black tupelo, tulip poplar) in the pulp mix	0.90[h]
Non-wood fibres	
With cotton linters in the pulp mix	0.69[i]
Without cotton linters in the pulp mix	0.61[j]

semi-chemical and chemi-mechanical) and category of fibres (softwood, hardwood, nonwood) for each paper. Based on the data of Table 6, the weight percentages of pulp constituents were calculated after conversion of fibre counts through the use of weight factors. The weight factor of a fibre is a dimensionless number derived by the ratio of its fibre coarseness (average weight per unit length) to that of a reference fibre, typically rag having a fibre coarseness of 0.180 mg/m. The total fibre count of each category was multiplied by its respective weight factor from Table 7 in order to obtain the equivalent weights and then, their percentages by weight of the total weight were calculated and reported to the nearest whole number (ISO 9184-1: 1990).

Table 6. Fibre count and proportion in paper grades

The above calculated proportions are presented in Table 8, while the occurrence of different genera and species identified in the papers (according to Tables 3, 4 and 5) are shown in Table 9. The great number of various species identified in paper grades, as presented in Table 9, shows that the raw materials in paper production processes are highly heterogeneous and this fact can be mainly attributed to recycling.

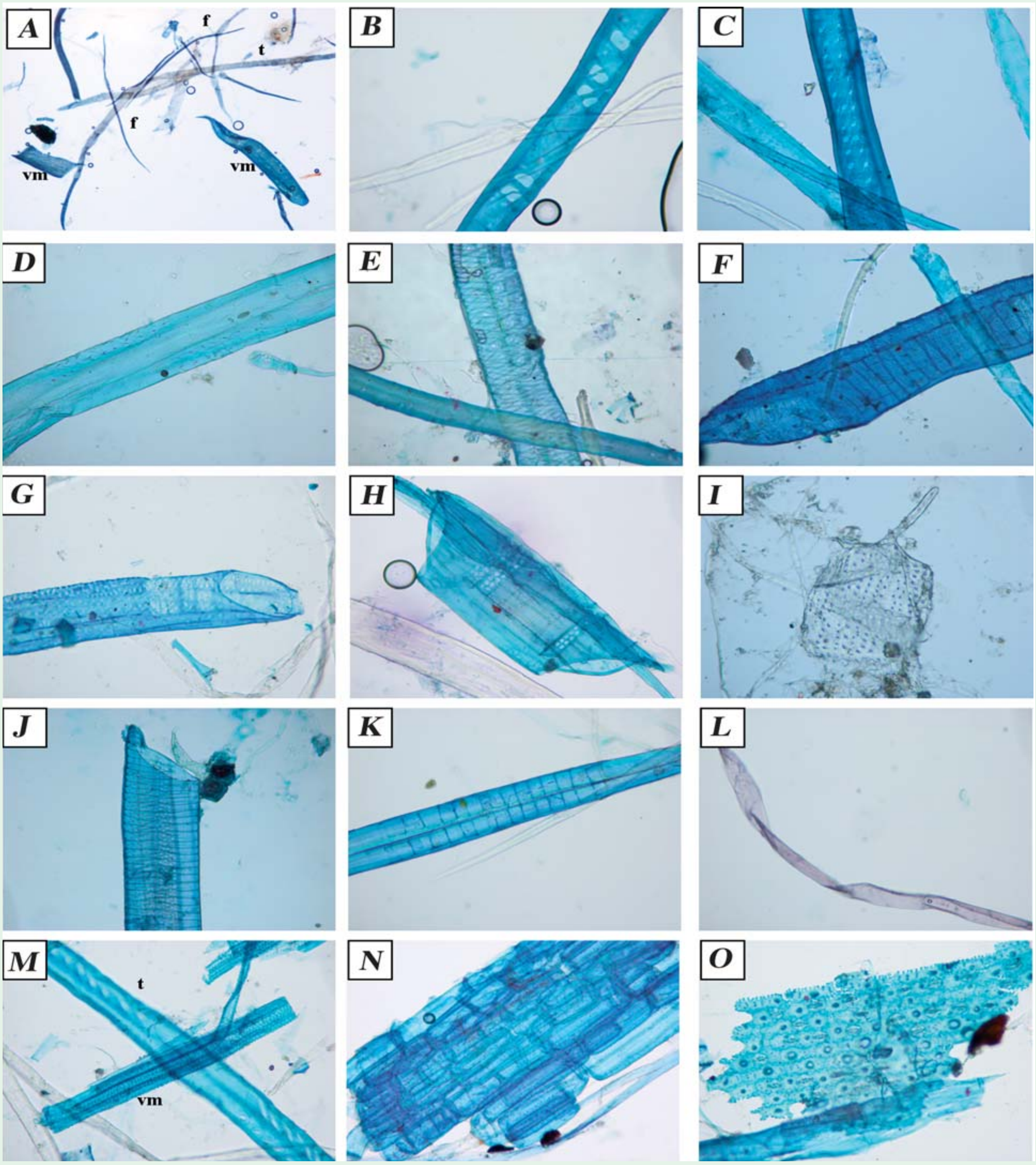
Table 7. Assignment of weight factors to the different fiber categories according to predetermined values recommended by ISO 9184-1: 1990

[a] weight factor recommended for most of the softwood unbleached chemical pulps (ISO 1990: 9184-1)

[b] average of weight factors of birch-aspen-poplar-beech: 0.5, sweet gum-black tupelo-tulip poplar: 0.8 and eucalyptus-oak: 0.45 (hardwood chemical pulps)
[c] average of weight factors of birch-aspen-poplar-beech: 0.5 and eucalyptus-oak: 0.45 (hardwood chemical pulps)
[d] average of weight factors of cotton linters: 1.25, bagasse pulp for paper grades: 0.75, abaca and jute pulps: 0.55, sisal pulp: 0.60, straw pulp for board grades: 0.60, bamboo pulp: 0.55, flax pulp: 0.8 and flax shives: 0.8
[e] average of weight factors of bagasse pulp for paper grades: 0.75, abaca and jute pulps: 0.55, sisal pulp: 0.60, straw pulp for board grades: 0.60, bamboo pulp: 0.55, flax pulp: 0.8 and flax shives: 0.8
[f] average of weight factors of softwood semi-chemical sulfite: 1.4 and softwood chemi-mechanical pulp (many species): 2.0
[g] average of weight factors of hardwood semi-chemical pulps, birch: 0.9 and gums: 1.3
[h] weight factor of hardwood semi-chemical pulps, birch: 0.9
[i] average of weight factors of cotton linters: 1.25, bagasse pulp for paper grades: 0.75, abaca and jute pulps: 0.55, sisal pulp: 0.60, straw pulp for board grades: 0.60, bamboo pulp: 0.55, flax pulp: 0.8 and flax shives: 0.8
[j] average of weight factors of bagasse pulp for paper grades: 0.75, abaca and

Groups/ Genera/ Species[1]	Linerboards														Corrugating medium								
	KL					TL			BB				WRL		SCF			RF					SCR
	125	140	170	170	225	100	115	170	105	110	110	160	140	145	127	150	150	95	105	110	125	160	112
Softwoods																							
Strobus and Sylvestris group	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Halepensis, Ponderosa, Taeda group	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Kesiya group																					+		
Larix or *Picea*	+	+	+	+		+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Pseudotsuga									+		+			+		+			+		+		
Abies	+															+							
Hardwoods																							
Betula	+	+		+	+	+	+	+	+	+	+		+	+	+	+	+	+		+	+	+	+
Eucalyptus	+	+	+			+		+	+	+	+	+	+	+	+		+	+		+	+		+
Populus	+	+		+	+	+		+	+	+	+		+	+	+	+	+	+	+	+	+	+	+
Fagus							+			+					+					+		+	
Tilia										+			+			+							
Nyssa sylvatica								+												+			
Liquidambar styraciflua									+		+			+		+							
Liriodendron tulipifera	+					+		+			+					+		+					
Nonwood fibres																							
Grasses/bast/ leaf fibres		+	+	+	+	+	+	+	+	+	+	+	+		+	+	+	+	+	+	+	+	+
Fruit fibres (cotton)			+		+			+		+	+		+	+	+	+		+	+	+	+		+
Vessel members									+	+	+			+		+		+					
Epidermal cells						+	+	+		+	+		+		+	+	+	+	+	+	+	+	+
Parenchyma cells		+	+			+		+	+	+	+	+			+	+	+	+	+	+	+	+	+

[1] *according to Tables 3, 4 and 5*



jute pulps: 0.55, sisal pulp: 0.60, straw pulp for board grades: 0.60, bamboo pulp: 0.55, flax pulp: 0.8 and flax shives: 0.8

Table 8 shows that in linerboards the proportion of chemical pulp was higher than semi-chemical and chemi-mechanical pulp only in three cases for KL grades (57-60%) and in one case for WRL grades (58%).

The lower proportions of chemical pulp in linerboards ranged between 31-49%. In corrugating medium papers, only in one case (RF grade) chemical pulp was found to be higher than semi-chemical and chemi-mechanical pulp (52%). It was much lower in all SCF grades (9-24%) and slightly lower in all other corrugating medium papers.

Paper grade		Weight (%)										
		Chemical pulp				Semi-chemical and chemi-mechanical pulp				Total		
		SW	HW	NW	Total	SW	HW	NW	Total	SW	HW	NW
Linerboards												
KL	125	29	27	4	60	7	30	3	40	36	57	7
KL	140	50	8	1	59	14	26	1	41	64	34	2
KL	170	32	14	0	46	42	11	2	54	74	24	2
KL	170	36	12	-	48	34	15	3	52	70	27	3
KL	225	42	15	-	57	25	15	3	43	67	30	3
TL	100	27	11	1	39	6	54	1	61	33	65	2
TL	115	17	29	1	47	28	20	5	53	45	49	6
TL	170	17	20	0	37	28	35	1	63	45	54	1
BB	105	4	25	2	31	36	31	2	69	40	56	4
BB	110	18	29	2	49	22	25	4	51	41	53	6
BB	110	11	32	1	44	19	31	6	56	30	63	7
BB	160	15	30	-	45	15	28	12	55	30	58	12
WRL	140	7	51	0	58	24	17	1	42	32	68	1
WRL	145	6	39	-	45	22	30	3	55	28	69	3
Corrugating medium												
SCF	127	5	18	1	24	43	32	1	76	48	50	2
SCF	150	5	7	1	12	35	47	6	88	39	54	7
SCF	150	4	4	1	9	42	46	3	91	46	50	4
RF	95	8	41	-	49	21	20	10	51	30	60	10
RF	105	24	21	-	45	22	29	4	55	46	50	4
RF	110	12	36	-	48	7	38	7	52	19	74	7
RF	125	29	20	3	52	28	18	2	48	57	38	5
RF	160	14	28	0	42	18	29	11	58	32	57	11
SHR	112	8	37	1	47	14	38	2	53	22	75	3

SW: softwood, HW: hardwoods, NW: non-wood"

Various wood and nonwood species were identified in all papers in different mixtures as shown in Table 9. Non wood fibers were found to participate in all papers with the lowest proportions (ranged between 1-12%) (see Table 8). In most papers hardwood content was higher (50-75%) than softwood and only five papers (4 KL and 1 RF grade) had lower hardwood weight (ranged between 27-38%).

Table 9. Occurrence of different genera and species identified in linerboards and corrugating medium

Figure 1. Microscopic appearance of softwood (B-E), hardwood (F-J) and nonwood (K-O) fibres in paper grades. A. Various fibre types (f : hardwood fibre, t : softwood tracheid, vm : hardwood vessel member), B : *Pinus* with window-like cross-field pits, C : *Pinus* with pinoid cross-field pits, D : *Picea or Larix* with piceoid cross-field pits, E : *Pseudotsuga* with spiral thickenings, F : *Betula*, G : *Fagus*, H : *Populus*, I : *Eucalyptus*, J : *Tilia*, K : bast fibres, L : cotton fibre, M : nonwood vessel member (vm) and softwood tracheid (t), N : nonwood parenchymatous cells, O : nonwood epidermal cells (A . 33X, B-O. 133X).

Table 8. Weight proportions of fibre components in linerboards and corrugating medium

CONCLUSION

This study addressed the complex problem of characterization of recycled paper of today. Compositional analysis techniques were employed for quantitative (fibre counts, weight proportions of fibre components) and qualitative (pulping processes, type of fibres) analysis of fibre based packaging raw materials aiming at the utilization of the available resources in an optimal manner. The results of this study together with the physical-mechanical characterization of paper will be used to evaluate the corrugated packaging behaviour in dependence to the grade papers composition by appropriate software modelling.

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