Morphological characteristics of recovered fibres used in the production of corrugated board in Greece

Recovered fibres

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***Abstract*—The structure of liners and flutings-medium commonly used by the corrugated packaging industry in Greece were determined on the basis of compositional analysis and morphology of their fibres. Standard fibre analysis techniques and microscopy were employed to identify the fibre components as regards their origin (softwood, hardwood, nonwood) and pulping methods, and to quantify them by using appropriate weight factors. Morphological characteristics of fibres including fibre dimensions, fibre length classes, coarseness, curl, kink, fines content, and fibrillation were assessed by a MorfiTrac device. As a result of the increasing share of recycled raw materials, the papers proved highly variable incorporating a large number of wood and nonwood fibre types. Softwoods and chemical pulp were the most important components in kraftliners, while hardwoods and semi chemical and chemi mechanical pulps were dominant in testliners and flutings. The paper grades were also varied greatly in the morphological characteristics of their fibre components. Kraftliners had the highest fibre dimensions, while kink, curl, fibrillation and fine content were higher in the recycled paper grades within liners and flutings. The quantitative distribution of fibre length classes further revealed the structural differences among the papers as the small fibre class 0.2-0.5 mm had a major contribution in the recycled based testliners and flutings, the fibre class 0.5-1.2 mm had the highest share in semi chemical flutings composed by relative short hardwood fibres, and the large classes 2.0-3.2 mm and 3.2-7.6 mm were found in higher percentages in kraftliners composed by long softwood fibres. Such data, combined with the physical-mechanical paper testing, can be useful in evaluating the performance of paper products which is needed for a sustainable packaging manufacturing.**

Keywords— liners; flutings; fibre composition; fibre morphological characteristics; fibre length classes

I. INTRODUCTION

The manufacture of corrugated board containers (boxes, trays, etc.) involves a production chain integrated by paper, corrugated board and container manufacturers, the majority of which are SMEs in Europe. Nowadays, corrugated board containers are mostly manufactured with recycled fibres, their share being up to 82% in Europe [1]. The greatest threat faced by the mentioned production chain is related to the lack of quality of recycled fibres as raw material. Pulps made from recycled paper are generally associated with some degradation of fibre properties or more fibre breakage relative to virgin fibres, and use of recycled materials also introduces contaminants [2]. One of the most important properties of packaging paper is its mechanical strength, which depends mostly on the length of the fibres it is composed [3]. Fibres are longer in virgin pulps (those coming from papers obtained from wood, i.e. not yet recycled). However, the high pressure on their demand - as well as the current economic and ecological restrictions in the use of forest based materials - has led to a situation in which very little quantity of virgin fibre enters the recycling chain. This means that the strength quality of recycled fibres - and by projection of the papers - is constantly decreasing with the on-going recycling cycles. In addition, packaging papers present a very high variability, which constitutes an obstacle when it comes to manufacturing containers having homogeneous properties fixed by the customers at specified costs.

The difficulty of predicting the properties of paper products produced from heterogeneous sources puts several limitations, which therefore lead to severe economic losses. The project “RF-CORRUG – Quality control of raw materials from recovered fibres for the production of corrugated board” under the National Strategic Reference Framework 2007–2013 ARCHIMEDES III deals with this common technical problem of the corrugated board industry. Specifically, the main objective of the project is to support the competitiveness of the corrugated board companies (mainly SMEs) by creating a software tool based on practical models that can predict packaging grade paper properties from data on fibres (qualitative, quantitative, morphological) used in their production.

It has been shown that inherent fibre characteristics including wood species, origin, age, and chemical composition significantly influence the final properties of paper [4]. It has been also proposed that proposed that in order to predict the properties of sheets made from mixtures of pulps, the fibre characteristics of the component pulps rather than the properties of sheets made from these pulps should be used [5]. 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 analyse both their time-varying structure and quality [6, 7].

This papers presents information on fibres (qualitative and quantitative analysis, morphology) used for corrugated packaging production in Greece. The data will be used thereafter to develop predictive models based on advanced statistical methods for the properties and performance of packaging papers.

II. MATERIALS AND METHODS

Thirty two (32) papers used by the corrugated packaging industry were used to analyse their fibre composition and morphological characteristics. The papers represent different qualities of liners (8 brown kraftliners, 8 brown testliners) and flutings-medium (8 semi chemical flutings, 8 recycled flutings) available in Greece for the production of corrugated board. The papers were provided by different paper suppliers from the global market coming from 11 European countries, Turkey, and USA. Information on the papers can be seen in Table 1.

TABLE I. INFORMATION ON THE SELECTED PACKAGING GRADE PAPERS

Paper ID	Grammage (g/m^2)	Origin	Classification[1]
Liners			
KL	125…190	France, Norway, Portugal, Switzerland, UK, USA	*Brown kraftliner*: predominantly made from primary kraft pulp
TL	120…170	Greece, Portugal, Romania, Spain, Turkey	*Brown testliner*: predominantly recycled fibre based, substance equal or over 120 g/m^2
Flutings-medium			
SC	110…160	Bulgaria, Croatia, Finland, Romania, Sweden, Switzerland, Spain	*Semi chemical fluting*: predominantly made from semi chemical primary fibres pulp
RF	100…130	Greece, Portugal, Spain, Turkey	*Recycled fluting – medium*: predominantly recycled fibre based, substance equal or over 100 g/m^2

[1] according to [8]

Qualitative and quantitative determination of the fibre components of the papers as regards the method of processing (chemical, mechanical, rag, semi-chemical and chemi-mechanical pulp) was carried out according to the Herzberg staining test method ISO 9184-3: 1990 [9]. Maceration was possible after boiling in water of small paper pieces and shaking in glass tubes. Microscope slides were prepared with fibres according to ISO 9184-1: 1990 [10]. After their staining with the Herzberg stain, fibres were viewed and systematically counted under an Eclipse 50i light microscope equipped with a digital Sight DS-5M-L1 camera (both Nikon). The fibres were classed into softwood, hardwood and nonwood fibre categories based on their morphology [11]. Weight percentages of different fibre categories were calculated by using predetermined weight factors recommended by ISO 9184-1: 1990 [10].

Fibre morphology of papers was evaluated by a MorfiTrac device (MFA-5000 Morphology Fiber & Shive Analyzer, BTG Sales) in duplicate samples of 1 g solids in 600 ml of water. The disintegration of the paper materials was made by an adaptation of ISO 5263-1: 2004 [12]. For obtaining the parameters of fibres (fibre morphology, curl, kink, fines, etc.) the following standards were followed: TAPPI T 233 cm-06 [13], T 234 cm-02 [14], and T 261 cm-00 [15].

III. RESULTS AND DISCUSSION

A. *Origin of fibres and weight percentages*

Microscopical identification of fibre components in pulp is a difficult task which involves several constrains. These are associated with the absence of morphological features employed in solid wood identification and the presence of similar species that are closely related in anatomical structure in the pulp mix. Also, the degradation (cutting and shortening, tearing, fibrillation, etc.) of fibres due to processing and repeated recycling puts additional restrictions. Therefore, the identification was limited to softwood and hardwood genera while nonwood components were grouped to the grasses, leaf and bast fibres, and cotton categories (Figure 1).

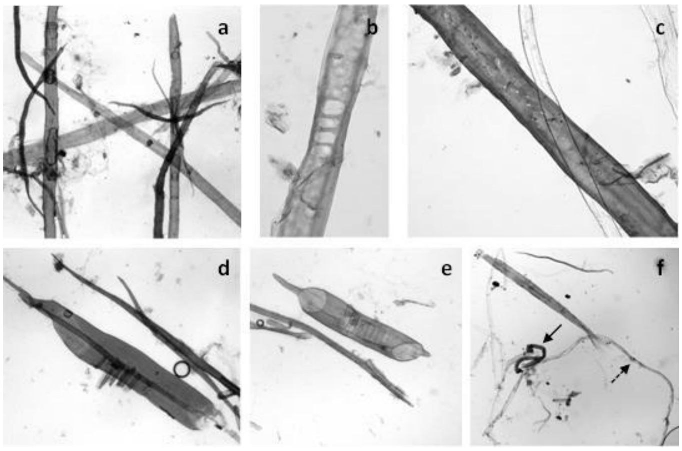

Fig. 1. Examples of different fibre types identified in the papers: softwood and hardwood fibres (a), *Pinus* (b), *Abies* (c), *Betula* (d), *Populus* (e), cell component (spiral vessel element) of a grass pointed with arrow and cotton pointed with dashed arrow (f)

All paper grades were highly variable containing 14-18 different wood and nonwood components (Table 2). Kraftliners and semi chemical flutings, predominantly made from primary fibres pulp, were less variable as compared to the recycled based papers, testliners and recycled flutings. Softwood fibres of *Pinus* and *Larix* or *Picea* were found in abundance in all papers. All other genera (*Abies*, *Pseudotsuga*, *Tsuga*) were present in small amounts. The major hardwood component in the papers was fibres of *Betula* followed by *Populus* and *Eucalyptus*. *Fagus* and *Tilia* were also frequently observed in testliners and semichemical flutings, respectively. Due to the recycling process, other hardwood genera such as *Acer*, *Alnus*,

Castanea, *Nyssa*, *Liriodendron*, *Liquidambar*, and *Quercus* were identified in the papers but in very small numbers. Finally, all papers contained nonwood fibres in small amounts. Similar results showing a highly variable fibre furnish of the European packaging grade papers were reported previously [16].

Hardwood was the main fibre component of flutings (66.99% and 65.23% per weight in semi chemical and fluting papers, respectively) and testliners (61.69%), while softwood fibres with a weight percentage of 56.31% dominated in kraftliners (Table 3). Nonwood fibres were found to be a significant weight fraction in the papers, especially in the recycled flutings with a mean weight percentage of 8.58%. As expected, chemical pulp was the most important component in kraftliners (60.85%) and semi chemical pulp in semi chemical flutings (73.46%). Chemical pulp was as low as 30.10% in testliners as a result of the high amounts of recycled fibres used in their production, while the share of the two pulp types was almost equal in the recycled flutings. The results on the quantitative analysis are comparable with the weight percentages of fibre components (origin and pulping methods of fibres) for representative papers used for the production of corrugated board in Spain [6, 7] and Europe [16].

TABLE II. OCCURRENCE OF SOFTWOOD, HARDWOOD AND NONWOOD FIBRES IN THE PAPERS[1]

Fibre categories/ Genera	Liners		Flutings-medium	
	KL	TL	SC	RF
Softwood				
Abies	*	*	-	*
Picea or Larix	**	**	**	**
Pinus	**	**	**	**
Pseudotsuga	*	*	*	*
Tsuga	*	*	*	*
Hardwood				
Acer	*	*	*	*
Alnus	-	*	*	*
Betula	**	**	**	**
Castanea	-	*	-	-
Eucalyptus	*	**	*	**
Fagus	*	**	*	*
Nyssa	-	-	-	*
Liriodendron	*	*	*	*
Liquidambar	-	*	*	*
Populus	*	**	**	**
Tilia	-	*	**	*
Quercus	*	-	-	*
Nonwood				
Grasses, leaf, bast	*	*	*	*
Cotton	*	*	*	*

[1] based on visual estimation of the relative amounts of different earlywood tracheids for softwoods, vessel elements for hardwoods, and fibres and associated cells for nonwood components

** frequent occurrence: high or moderate numbers of the different fibre types

* less frequent occurrence: small or very small numbers of the different fibre types

The results on fibre composition reflected the differences in quality between the paper grades. The stiffer kraftliners, being less variable and having generally higher softwood and chemical pulp contents, represent better qualities of linerboard than the testliners. The exclusive use of recycled fibres in the production of recycled flutings places them as the most variable grade from both qualitative and quantitative standpoints.

TABLE III. WEIGHT PERCENTAGES OF FIBRE COMPONENTS IN THE PAPERS[1]

Fibre categories	Liners		Flutings-medium	
	KL	TL	SC	RF
Origin of fibres[2]				
Softwood	56.31 (14.63)	33.19 (9.89)	29.63 (12.76)	26.19 (7.05)
Hardwood	38.89 (13.93)	61.69 (7.12)	66.99 (12.18)	65.23 (7.09)
Nonwood	4.80 (2.02)	5.12 (4.44)	3.38 (2.83)	8.58 (1.81)
Types of pulp[3]				
Chemical	60.85 (5.89)	30.10 (20.18)	26.54 (12.64)	51.19 (3.64)
Semi chemical and chemi mechanical	39.15 (5.89)	69.90 (20.18)	73.46 (12.64)	48.81 (3.64)

[1] mean values and standard deviations in parenthesis

[2] based on their morphology

[3] based on the colour reactions of fibres stained by the Herzberg stain. Mechanical and rag types of pulp were regarded as traces as their percentages were less than 2% in all papers

B. Fibre morphology

TABLE IV. MORPHOLOGY OF FIBRE COMPONENTS IN THE PAPERS[1]

Fibre properties	Liners		Flutings-medium	
	KL	TL	SC	RF
Fibre length, mm				
Arithmetic	0.75 (0.11)	0.49 (0.01)	0.63 (0.11)	0.51 (0.03)
Length weighted	1.68 (0.27)	1.05 (0.03)	1.01 (0.10)	1.12 (0.09)
Weight weighted	2.49 (0.27)	1.78 (0.08)	1.42 (0.12)	1.90 (0.25)
Fibre width, µm	24.38 (2.11)	20.60 (0.32)	24.16 (0.80)	21.04 (0.61)
Cell wall thickness, µm	6.20 (0.49)	5.42 (0.19)	5.72 (0.43)	5.66 (0.13)
Cross sectional area, µm²	431.04 (40.25)	360.80 (19.91)	382.30 (45.27)	383.28 (11.95)
Fibre volume index, 106 µm³	0.64 (0.13)	0.35 (0.01)	0.36 (0.05)	0.37 (0.01)
Coarseness, mg/m	0.20 (0.02)	0.19 (0.01)	0.16 (0.02)	0.18 (0.01)
Curl, %	12.12 (0.64)	12.62 (1.12)	9.48 (2.04)	11.74 (0.84)
Kink index, l/m	551.5 (155.3)	913.9 (162.3)	507.1 (201.6)	794.6 (126.1)
Fibrillation, %	11.18 (2.50)	13.71 (0.97)	11.90 (2.11)	13.19 (1.42)
Fines, %	29.30 (3.55)	33.94 (1.07)	23.30 (7.53)	33.17 (2.34)
Fibres per mg	6,659 (1,506)	10,858 (106)	10,217 (1,602)	10,635 (531)

1 mean values and standard deviations in parenthesis

As a result of the diverse raw materials used for their production, the different paper grades varied greatly in the morphological characteristics of fibre components (Table 4).

TABLE V. DISTRIBUTION OF FIBRE LENGTH FRACTIONS IN THE PAPERS

Paper ID/	Distribution, %

Fibre length type	0.0-0.2 mm	0.2-0.5 mm	0.5-1.2 mm	1.2-2.0 mm	2.0-3.2 mm	3.2-7.6 mm
KL						
Arithmetic	29.32	23.58	27.28	10.28	7.28	2.32
Length weighted	3.78	10.90	29.34	21.04	23.46	11.48
Weight weighted	0.30	2.46	15.38	20.12	35.18	26.56
TL						
Arithmetic	34.44	29.28	28.80	4.82	2.16	0.50
Length weighted	6.54	20.16	44.00	14.66	10.92	3.70
Weight weighted	0.78	6.80	32.74	21.02	25.56	13.10
SC						
Arithmetic	23.18	22.18	44.14	9.00	1.20	0.28
Length weighted	3.96	12.80	57.36	19.64	4.54	1.72
Weight weighted	0.52	4.80	49.28	27.84	10.94	6.64
RF						
Arithmetic	31.80	28.65	31.15	5.33	2.38	0.65
Length weighted	5.70	18.35	45.00	14.93	10.98	5.00
Weight weighted	0.63	5.83	32.20	20.03	24.38	17.05

Kraftliners, containing a significant amount of larger and thicker softwood fibres, had the highest fibre dimensions. Especially, the length weighted length, which is directly correlated to paper properties [17], had a mean value of 1.68 mm and was much higher than the values 1.01-1.12 mm in the other grades. Semi chemical flutings, composed mainly by hardwood fibres, had the lowest coarseness mean value than the other grades. The stiff hardwood fibres were also provided semi chemical flutings with high mean fibre width (24.16 mm). Kink, curl, fibrillation and fine content were higher in the recycled grades than the respective virgin based within the liners and flutings categories. This was due to refining and beating during the repeated recycling cycles, which also helped to straighten the fibres at some extent. Fibrillation increases the bonding ability of recycled fibres but there is a limit [18]. Fines adversely affect paper structure and properties [19] but as all the grades incorporate recycled fibres in their furnish it was rational to find relatively high fines content values, especially in the recycled based testliners (33.94%) and recycled flutings (33.17%). Fibre population is associated positively to a great number of fibre and paper properties [20], but this parameter when viewed alone cannot explain the differences in paper quality. For example, kraftliners have fewer fibres per mg (6,659) than the testliners (10,858) but their quality is better.

The structural differences of the papers were reflected by the quantitative distribution of fibre length (arithmetic, length weighted, weight weighted) fractions in the range 0.0-7.6 mm (Table 5). The percentage of fines was represented by the fibre class 0.0-0.2 mm. Arithmetically, the share of fines is quite high in all papers, especially the recycled based. However, the quantity of fines is not related directly to paper properties but rather to bonding of the fibre network [21]. The dominant fibre class in all papers was the class 0.5-1.2 mm, especially in semi chemical flutings which are composed mainly by virgin hardwood fibres with lengths falling within this range. The small fibre class 0.2-0.5 mm has a major contribution in testliners and recycled flutings, which are mostly made by fibres reduced in length by repeated recycling. Fibre class 1.2-2.0 mm has a significant share in all papers, while the large fibre classes 2.0-3.2 mm and 3.2-7.6 mm were found in higher percentages in kraftliners due to the high presence of softwood fibres.

IV. CONCLUSIONS

The compositional analysis (qualitative, quantitative) and morphological characterisation of fibre components of packaging grade papers provided essential information on the recycled raw materials used in their production. Such diagnostics assessing the potential quality distribution of fibres available for the production of liners and flutings are highly needed to utilize the available heterogeneous resources in an optimal manner. The reliable characterisation of raw pulp materials is not only useful for a continuous control of packaging fibre sources but can be also used to evaluate the influence it has on the final properties and performance of paper products.

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