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# Accelerated Ageing of Newsprint Paper: Changes in Swelling Ability, WRV and Electrokinetic Properties of Fibres

## Abstract

*The present paper deals with the effect of accelerated ageing on the ability of fibres to undergo saturation with water and the corresponding swelling kinetics. Changes in the surface charge of aged paper fibres were also investigated. Accelerated ageing was performed with newsprint paper at 98 °C and 50% RH during 0, 3, 5, 7, 10, 15, 20 and 30 days. The rate and maximum swelling of accelerated aged paper in water were obtained with a modified monitoring unit measuring wood swelling ability. Since paper swells extremely fast in water, even at 30 °C, this apparatus made it possible for the first time to obtain accurate kinetic data on aged paper swelling in water. The polyelectrolyte titration technique was used to investigate changes in the surface charge on fibres from accelerated aged paper.*

**Key words:** accelerated ageing, water retention value, swelling kinetics, fibres surface charge.

## Introduction

Thermal and accelerated ageing has been shown to affect the void structure of cellulose and the ability of paper to retain water [1]. This ability is expressed by the water retention value (WRV), which is related to the capacity of fibres structure to absorb water under specified conditions. When these cellulosic fibre structures become impermeable to water, the WRV decreases [1 - 6]. This phenomenon is usually called hornification, i.e. the keratinisation of cellulose fibres. Hornification occurs during repeated rewetting and drying processes in recycling or is due to heating within the accelerated ageing process. Hornification manifests itself as increased brittleness in paper [7] and it reduces the flexibility of fibres and the tensile strength of paper. According to Young [8], a convincing correlation between the concentration of acid groups in fibres, swelling and water retention in the paper exists which is likely connected to changes linked to hydrolysis.

These hydrolysis-promoted changes appear both at the microstructure and macrostructure levels. A generally accepted model of the cell wall structure com-

prises cellulose microfibrils (**Figure 1**), together with the lignin-hemicellulose matrix surrounding them, forming an interrupted lamella structure [9 - 11]. The intralamellar space within the lignin-hemicellulose matrix and between microfibrils forms a small pore fraction called micropores [9 - 11].

A key mode of cellulose degradation involves the disintegration of supramolecular structures formed by hydrogen bonds between OH-groups, considered as the major factor controlling the structure and the physical property of cellulose [12 - 14]. Inside the structure there are multiple levels of cellulose hydrogen links: intramolecular bonds, intramolecular hydrogen bonds and hydrogen bonds between the cellulose surface and degradation products [15]. The formation of intramolecular hydrogen bonds has been proven to contribute directly to certain cellulose physical properties such as crystallinity and solubility in various solvents of different polarity. It also affects the relative reactivity of the cellulose [13]. It is hypothesised that the hydrogen bonds are responsible for the ability of cellulose fibres to retain water and influence the swelling rate.

To measure the swelling ability of pulp fibres in water, various methods are used. The most frequent method is the centrifugal determination of the water retention value (WRV), which is an empirical measure of the capacity of a test sample of fibres to hold water. The WRV is defined as a ratio of the mass of water retained after centrifugation under specified conditions by a wet pulp sample to the oven-dry mass of the same pulp sam-

ple. This method is suitable to determine the maximal capacity of cellulose fibres to retain water up to the saturation point. However, it cannot be used to monitor the rate (kinetics) of water absorption and corresponding swelling.

The swelling kinetics due to water absorption by cellulose fibres is usually observed microscopically. The dimensional changes of cellulose fibres are recorded at certain time intervals from the initial contact of a sample with aqueous media [16]. Samples with a certain initial diameter are placed in a swelling medium, and the diameter of the samples is recorded by digital video camera. If the actual swelling degree of fibres differs from its equilibrium value, the network will swell to reach the equilibrium concentration. This volume change can be monitored through following the change in the size or mass of the fibre samples in time.

To observe changes in the dimension of fibres, a modified measuring device was used originally designed by Solar et al [17] for continuous measurement of wood material swelling. The principle of monitoring lies in determining dimensional changes in pulp sheets immersed in water by dimensional sensors and in simultaneously converting the changes into electronic signals. In our investigation of paper swelling, a glass monitoring unit developed in our laboratory was used.

The work is aimed at presenting a new means of measuring paper swelling kinetics. The change the specific charge density of pulp fibres during accelerated ageing was also investigated.

## Experimental

### Raw material

Commercial wood-containing newsprint paper (grammage 45 g/m<sup>2</sup>) with pH 4.5 – 5.0 (determined by cold extraction) consisting of mechanically bleached ground wood pulp (55%), bleached sulphite pulp (20%), recycled fibres (15%) and clay (10%) was used in all experiments.

### Fibre sample

Samples in a dried state were used. They were disintegrated in deionized water, swollen for 10 minutes and used for poly-electrolyte titration.

### Accelerated ageing at 98 °C

Paper samples were conditioned according to TAPPI T402 om -93 at 23 ± 1 °C at a relative humidity of air RH = 50 ± 2%. The samples were subsequently aged according to ISO 5630-05 at 98 ± 2 °C and 50% RH, corresponding to a paper humidity of 4 - 5%. Twenty sheets of paper (A4 format) were encapsulated inside a PET/Al/ PE composite foil (Tenofan Al/116S) by sealing off all four edges using a Polystar 30D impulse tong sealer (Rische&Herfurth, Hamburg, Germany). This bag was put into another PET/Al/PE bag and completely sealed off. Batches of samples were put into a thermostat for 0, 3, 5, 7, 10, 15, 20, 30 and 60 days and kept at 98 ± 2 °C according to ASTM D 6819 – 02: “Standard test method for accelerated ageing of printing and writing paper by dry oven exposure apparatus”, in which sealed glass tubes were replaced by a composite foil made of polyethylene / aluminium / polypropylene (Tenofan Al / 116S). Humidity inside the bag during accelerated ageing was 50 ± 2%, and the free air volume in the bag 5 ± 1 ml. After ageing, the papers were conditioned for testing according to TAPPI T402 om -93.

### Water retention value

To calculate the WRV the following expression

$$WRV = \frac{m_1 - m_2}{m_2} 100\% \quad (1)$$

was used, where  $m_1$  and  $m_2$  are the masses of centrifugated wet pulp and dry pulp, respectively.

To determine the WRV of the samples, the method proposed by Jayme [18] was applied. Centrifugation was carried out at 3000 r.p.m. for 15 min. After centrifugation, the samples were weighted and subsequently dried in an oven at 105 ± 2 °C

to a constant mass. Data points represent the average of four replicates, and the standard deviation is lesser than 5.1%.

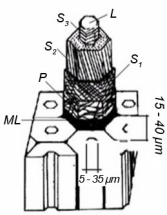
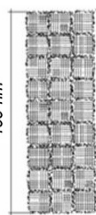
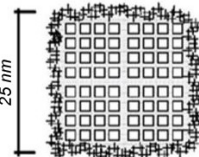
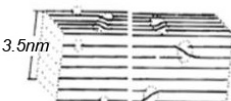
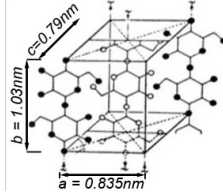
### Measuring the swelling kinetics

To monitor the swelling kinetics of cellulose fibres, a modified measuring unit originally designed for following wood material swelling [17] was used. The unit was modified for our purposes, and detailed visualisation of the sensors and glass prisms is provided in *Figure 2* (see page 110).

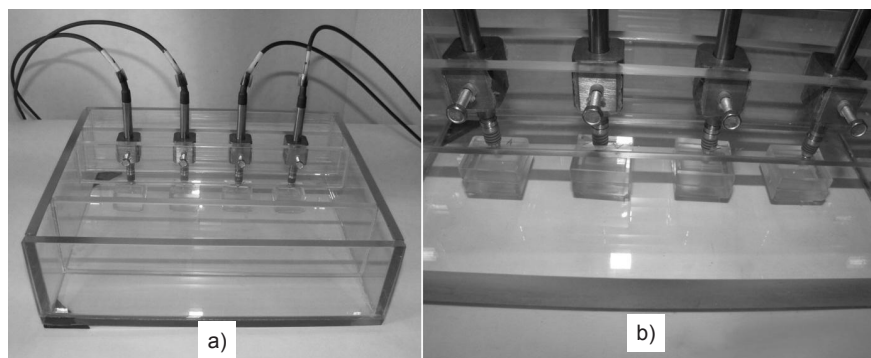
Samples in the form of sheets with an initial diameter of 4 cm<sup>2</sup> were used for the experiment. The swelling was measured for paper thickness (0.07 ± 0.01 mm)

and grammage 45 ± 1 g/m<sup>2</sup>. A measurement was made to determine the thickness of the paper under a total load of 9.92 ± 0.12 g/cm<sup>2</sup>. The total load is composed of the weight of the glass prism (35.823 ± 0.438 g) and the load of the sensors. Swelling manifests itself as an increase in the paper sample thickness, causing a gradual upstroke (shift; lift) of the prism. The rate of prism movement is transformed into a continually evaluated electric signal.

The temperature of swelling media was 30 ± 2 °C. All samples were air-conditioned, with the initial moisture content of the paper ranging from 4.1 to 5%. The first 60 seconds were measured at an

Scale, nm	Scale	Size of elements	Elements
100 000	100 µm	Wood cell wall width: 15-40 µm	
10 000	10 µm		
1 000	1 µm	Macrofibril width: Φ 400 nm interfibrillar space: Φ 10 nm	
100	100 nm		
10	10 nm	Microfibril width: 25 nm intermicrofibrillar space: Φ 6 nm	
		Elementary fibril width: 3.5 nm interfibrillar space: Φ 1 nm	
1	1 nm	Crystal lattice of cellulose b = 1.030 nm a = 0.835 nm	
0	0 nm		methanol, ethanol 0.44 nm O <sub>3</sub> 0.31 nm O <sub>2</sub> 0.28 nm

*Figure 1. Visualisation of primary and secondary cell-wall structure.*



**Figure 2.** Modified glass monitoring unit (a) and detailed visualisation of sensors and glass prisms (b).

terval of 0.1 seconds and then subsequent measurements made at 1 second intervals for further approximately 120 minutes. The final values of swelling obtained represent the average of six measurements.

During the swelling, dimensional changes of the samples investigated (sheets) are converted to electronic signals. The electronic signals obtained are evaluated on a PC as a time dependence of the swelling [17]. The swelling is determined as the difference of the actual and initial dimensions of the samples and expressed in percentages. Computation of the course of the sample swelling in the plane perpendicular to the surface was performed applying the formula [17]:

$$S = \frac{(F_{t_i} - F_0)}{F_0} 100\% \quad (2)$$

where,  $S$  is the swelling in the plane perpendicular to the paper sample,  $F_{t_i}$  is the thickness of the paper during monitoring at time  $t_i$ ,  $t_i$  is any time within the interval from 0 to 8000 s, and  $F_0$  is the initial thickness of the paper at the initial moisture content.

The relative rate constant  $k$  of the swelling first-fast phase

$$k = \frac{\Delta S}{\Delta t} \quad (3)$$

**Table 1.** Maximal swelling values  $S$  and swelling rate constants  $k$  of unaged and aged paper; SD standard deviation.

Accelerated ageing time, days	k, s <sup>-1</sup>	SD	S, %	SD	pH	SD
0	29.25	2.78	63.75	3.56	7.2	0.2
3	2.67	0.54	29.45	5.28	4.2	0.1
5	2.42	0.62	28.57	1.98	4.2	0.1
7	2.58	0.44	24.96	6.55	5.1	0.1
15	1.50	0.36	19.53	6.41	4.5	0.2
20	1.89	0.47	14.28	2.26	4.6	0.1
30	1.81	0.43	11.76	3.95	4.8	0.1

is computed from the time evolution of swelling (**Figure 3**). Exact details on the evaluation procedure, adopted in this work are described elsewhere [17].

It should be stressed that the device used even enables to follow paper swelling, which is usually too fast to monitor by optical techniques traditionally used.

#### Electrokinetic measurement

Fibre charge was determined using a particle charge detector - Mütek<sup>TM</sup> PCD02 (BTG Instruments GmbH), which comprised a cylindrical plastic vessel and a vertically reciprocating displacer piston fitted inside. The suspension is transferred into the cylindrical vessel and charged particles in colloidal solution get partially adsorbed on the cylinder and piston surface. When the piston moves up and down, a charge is built up depending upon characteristics of the colloidal solution. Electrodes measure the induced streaming potential thus built up. To measure the fibre charge, paper (0.3 g) was mixed with 5 ml of 0.001 N cationic electrolyte poly(diallyldimethylammonium chloride), abbreviated further as poly(dadmac), and stirred with a magnetic stirrer for 30 min to completely neutralise anionic charge in the fibre by poly(dadmac). After the elapsing of the reaction time, fibres in the suspension were removed by sieving. Filtrate was put

into a cell and titred with 0.001 N anionic polyelectrolyte sodium polyethylenesulphate (PES-Na) to the end point [19]. The fibre charge was calculated according to [20] as

$$q = f_c n V w^{-1} \quad (4)$$

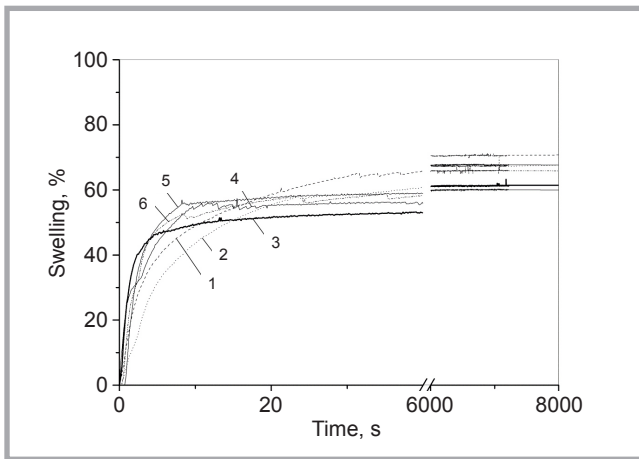
where,  $f_c$  is the conversion factor for the unit of charge density (in this case 1000),  $n$  the concentration of standard polyelectrolyte, in mol l<sup>-1</sup>;  $V$  the volume of polyelectrolyte titrated in ml; and  $w$  is the content of material dissolved or dispersed in 10 ml of the sample solution, in ml or mg. All the values presented are the mean values of three measurements, with the standard deviation being less than 0.67 µeq/g.

## Results and discussion

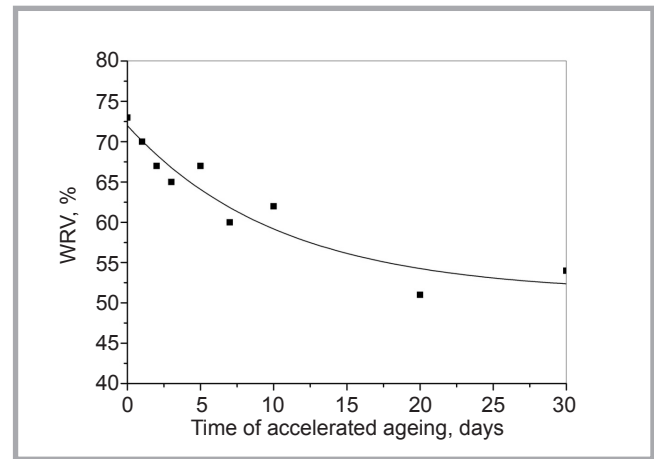
The numeric data collected are gathered in **Table 1** and relationships between the quantities measured are illustrated in the Figures. **Figure 4** demonstrates the gradual decrease in WRV during the accelerated ageing. Our results thus correspond to those obtained by Kato and Cameron [1], who observed a decrease in the WRV while investigating, however, filter paper aged at 160 °C in air. Their results indicated that the hornification process is one of closing (impermeability) the structure of cellulose fibres to water due to irreversible hydrogen bond formation between the micro-fibrils and other structural units of cellulose fibres.

The size of pores is reduced, the structure of paper becomes more compact, and the paper becomes significantly more brittle. After ageing, the wet structure resembles more closely a dry one, suggesting that water cannot expand the structure to the same extent. It is postulated that an increase in local ordering of ageing creates a structure more resistant to disruption by water [5]. A higher swellability of the samples is characterized by a higher WRV. As a result, the microstructure partially collapses and the water retention value of paper decreases. After 30 days of accelerated ageing the loss of WRV reached about 26% (54% WRV for 30 days) compared with non-aged samples. Jablonsky et al [7, 21, 22] confirmed the decrease in folding endurance and brittleness index during accelerated ageing, which indicates that wood-containing newsprint paper becomes somewhat brittle.





**Figure 3.** Swelling profiles of unaged paper with initial moisture content 4.1%. Six times (no. 1 – 6) measured swelling profiles of unaged paper.



**Figure 4.** Water retention values for aged paper. Data points represent the average of four replicates, with the standard deviation being less than 5.1% [22].

Determination of WRV allows to measure the amount of water located in the fibre structure in the saturation point conditions. The method for the continual following of paper swelling kinetics in various media was performed on an apparatus developed for wood stick swelling measurement [17]. This apparatus made it possible to obtain accurate rate data on paper swelling as well. This method and equipment was used to measure the swelling of recycled fibres in various works [23 – 26].

**Figure 4** is a graph of the unaged paper swelling profile. The increase in the swelling in % is plotted against time (second). Kinetic curves indicate two marked phases: a short and fast initial phase, running for only a few seconds, with a high swelling gain, where the swelling rate reaches a maximum, followed by a long but a slow phase with a poor swelling increment, where the swelling rate approaches zero (final swelling). In this phase, fibres are fully saturated [26]. The maximum equilibrium swelling is reached after about 1 hour of swelling in water at 30 °C.

Swelling kinetics were evaluated by regression analysis of the following equation

$$y_1 = A(1 - e^{-kt}) \quad (5)$$

where:  $y_1$  is the swelling in %,  $A$  is the parameter of maximal swelling induced by the first fast initial phase in %,  $k$  is the rate constant determined by the velocity of limiting (maximal) value  $A$  obtained in  $s^{-1}$ ,  $t$  is the swelling time in s.

The results in **Table 1** provide the maximal swelling and swelling rate of accelerated aged paper. The results show a decrease in the paper swelling rate and maximal swelling values with prolonged accelerated ageing.

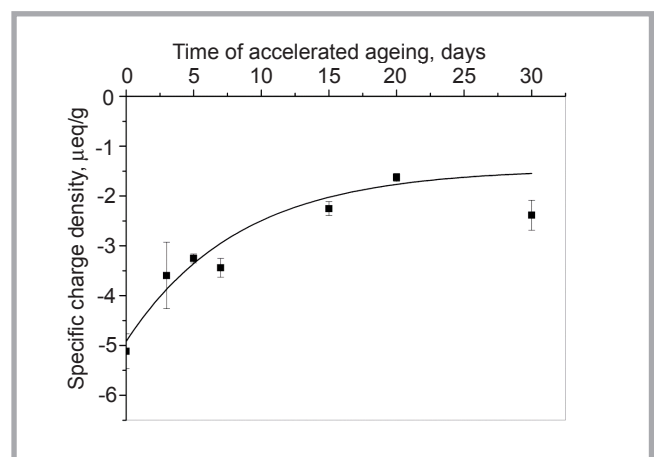
The rate constant for unaged samples is  $29.25 s^{-1}$  and the maximal swelling value is 63.75%. This is the highest rate constant, with ageing leading to its substantial decrease. The rate constant for 3-days aged paper is 10.95 times lower and the maximal swelling 2.16 times smaller compared with the unaged sample. Based on the ageing-dependent rate constant it can be assumed that the hornification, caused by a process of closing the cellulose fibre structure to water during ageing, evolves, as confirmed by other authors [1 – 5]. Fibres immersed in water are wetted on the surface and then the water penetration continues to interfibre areas, lumens and capillary cell walls. The penetration rate for liquids is higher in larger capillaries, directing the liquid to narrower capillaries with a

much higher suction capacity. With paper ageing the capillaries' diameter decreases and the suction rate is reduced. Monitoring of the swelling rate at the initial phase could be a good technique to explain the hornification process.

The results reported here may be interpreted against the background of the parallelogram provided that due consideration is given to the limitations of the experimental procedure adopted, particularly to the following factors:

- the total load on the pressure foot was constant at  $9.92 \pm 0.12 g/cm^2$
- air entrapped in the pores because of the glass prisms in the apparatus may impede the sorption process
- the temperature of swelling media:  $30 \pm 2 ^\circ C$
- the swelling is followed continuously.

Fibre walls have a porous structure and the solid-liquid interface is negatively charged due to dissociation of various ionizable groups such as carboxylic, sulphonic, phenolic and hydroxyl [27].



**Figure 5.** Specific surface charge density of fibres originating from accelerated aged paper. Data points represent the average of 3 replicates, with the standard deviation being less than 0.67 µeq/g.

These groups cause the fibre to carry a negative charge. The surface charge density of different cellulosic fibres is dependent on the pulping process (i.e. mechanical or chemical pulping) and bleaching sequences [28, 29]. This phenomenon is clearly documented in several papers [27 - 29]. As an example, the values of negative charge of different types of unbleached pulp originating from various mills in Sweden are as follows:

unbleached softwood TMP from Holmen - 11  $\mu\text{eq/g}$ ,  
 kraft/SW - 3.4  $\mu\text{eq/g}$ ,  
 kraft/HW - 6.3  $\mu\text{eq/g}$ ,  
 NSSC/HW - 6.0  $\mu\text{eq/g}$ ,  
 TMP/SW - 11  $\mu\text{eq/g}$  and  
 different bleaching sequences for hardwood kraft pulp (from AssiDomän, Frövi):  
 DED - 5.3  $\mu\text{eq/g}$ ,  
 Q(PO)P - 5.7  $\mu\text{eq/g}$  and  
 HA/Q(PO)P - 3.6  $\mu\text{eq/g}$ .

The results from determination of the surface charge density for unaged and aged papers are shown in **Figure 5**. The highest negative charge was determined for unaged samples (-5.1  $\mu\text{eq/g}$ ). All paper fibres (unaged and aged paper) bore a negative charge. By prolonging the ageing time, the fibre's negative charge decreases from -5.1  $\mu\text{eq/g}$  to -1.6  $\mu\text{eq/g}$ .

Recently it has been shown that the location of the charges in the fibre wall has a great influence on their effect [30 - 32]. A higher concentration of charges at the fibre surface results in a greater effect on paper strength properties [33]. Barzyk [30] found that carboxylic enrichment of fibre surfaces results in improved paper strength properties. These results imply that specific acid group topochemistries could be engineered in pulp fibres to increase sheet strength.

On the other hand, it is known [21] that the mechanical properties of paper decrease during accelerated ageing. The degradation of paper is associated with the formation of low molecular products such as formic, acetic and lactic acids, among others. The formation of these acids leads to a self-promoting hydrolytic degradation chain reaction, or auto-catalysis [34]. The influence of the oxidation process results in the formation and release of degradation products containing a carbonyl group (C=O) and double bond (C=C) [35].

According to Zou et al. [36] the fibre strength loss is caused by the depolymerisation of the cellulose due to acid-catalysed hydrolysis. These authors published various results in 1996. It is unlikely that such an increase in acidity would have a significant effect on the rate of cellulose hydrolysis in paper. Kinetic data published by Zou et al. [37] indicate that for papers with a pH-value above 4.5, the contribution of acid catalysis to the rate of cellulose depolymerisation by hydrolysis is only of minor importance. However, according to studies recently performed [38, 39], acid hydrolysis causes a chain scission of cellulose macromolecules, generating carbohydrate fragments. These fragments are oxidised to carboxylic acids, which generate a cycle of oxidation and hydrolysis in consequence of enhancing the acidity of paper, and cause the autocatalytic degradation of paper.

Changes in the surface charge of fibres from accelerated aged paper are supposed to be due to pH changes of aged pulp fibres or/and the degradation of the paper. The acids are located in the whole volume of the pulp fibre wall and can influence the fibre surface pH. Changes in pH can vary the surface charge by influencing the functional group dissociation. It is known that the negative charge of pulp fibres decreases with the lowering of pH. On the other hand, a decrease in the negative charge of fibres could have an impact on their flexibility. This finding confirmed the results of the brittleness index determined [19], because the charges are important for various properties, such as cell wall flexibility and paper strength [29, 40].

## Conclusion

The main conclusion drawn from this study lies in the continuous measurement of pulp fibre swelling and maximal water retention (WRV) for different aged paper. The method and apparatus described made it possible to obtain accurate kinetic data on paper swelling. It was found that the swelling rate of paper decreases due to its ageing, with the WRV value decreasing as well. The changes in WRV can be explained by hornification during ageing or fibre pH changes. The same trend is observed in the case of maximal swelling and the water retention value. Furthermore it was also found that the

negative charge of samples decreases with a prolonged ageing time.



## Acknowledgements

This study is a result of project implementation: APVV 0850-11, supported by the Slovak Research and Development Agency (SRDA), Slovakia and Finalisation of the Infrastructure of the National Center for Research and Application of Renewable Energy Sources (ITMS: 26240120028), supported by the Research & Development Operational Programme funded by the ERDF, and VEGA project No. 1/0985/12 and 1/0775/13.

## References

1. Kato KL, Cameron RE, *Cellulose* 1999; 6, 1: 23-40.
2. Stone JE, Scallan AM, Abrahamson B. *Svensk Papperstidning - Nordisk Cellulose* 1968; 71, 19: 687-694.
3. Scallan AM. *Wood Science* 1974; 6, 3: 266-271.
4. Klungness JH, Caulfield DF. *Tappi Journal* 1982; 65, 12: 94-97.
5. Kato KL, Cameron RE. *Journal of Applied Polymer Science* 1999; 74, 6: 1465-1477.
6. Olejnik K. *Fibers & Textile in Eastern Europe* 2012; 20, 1: 113-116.
7. Jablonsky M, Katuscak S, Holubkova S, Hrobonova K, Lehotay J. *Restaurator* 2011; 32, 4: 318-347.
8. Young RA, *Cellulose: Structure, Modification and Hydrolysis*, Wiley, New York, 1986, pp. 91-128.
9. Stone JE, Scallan AM. *Tappi Journal* 1967; 50, 10: 496-501.
10. Lindström T. *International Fiber Science and Technology Series 8, Paper Structure and Properties*. Marcel Dekker Inc., New York, 1986, pp. 99-120.
11. Wang X. *Improving the papermaking properties of kraft pulp by controlling hornification and internal fibrillation*. Helsinki University of Technology, Finland, 2006.
12. Lazareva TG, Vashuk V. *International Journal of Modern Physics B* 1996; 10, 23/24: 2983-2989.
13. Kondo T. *Journal of Polymer Science Part 1997*; 35, 4: 717-723.
14. Heiner PA, Teleman O. *Langmuir* 1997; 13, 3: 511-518.
15. Xiang Q, Kim JS, Lee YY. *Applied biochemistry and biotechnology* 2003; 105: 337-352.
16. Hajsz T, Csetneki I, Filipcsei G, Zrinyi M. *Physical Chemistry Chemical Physics* 2006; 8: 977-984.
17. Solar R, Mamon M, Kurjatko S, Lang R, Vacek V. *Drvna Industrija* 2006; 57, 2: 75-82.
18. Jayme G. *Tappi Journal* 1958; 41, 11: 180-183.

19. Sood YV, Tyagi R, Tyagim S, Pande P. *Journal of Scientific and Industrial Research* 2010; 69, 4: 300-304.
20. Suty S and Luzakova V. *Colloids and Surfaces A: Physicochemical and Engineering Aspects* 1998; 139, 3: 271-278.
21. Jablonsky M, Katuscak S, Kacik F, Kacikova D. *Cellulose Chemistry and Technology* 2011; 45, 5-6: 405-411.
22. Suty S, Petrilakova K, Katuscak S, Kirschnerova S, Jablonsky M, Vizarova K, Vrska M. *Cellulose Chemistry and Technology* 2012; 46, 9-10: 631-635.
23. Geffert A, Geffertová J. *Papír a celulóza* 2010; 65, 9: 253-253.
24. Geffert A, Geffertová J, Vacek V. Swelling of the recycled pulp fibers. In: *VII International symposium - Selected processes at the wood processing*. Štúrovo, 2009.
25. Geffertová J, Geffert A. Material Recycling - Trends and Perspectives. In: *In-Tech 2012*. p. 280.
26. Letkova E, Letko M, Vrška M. *Chemical Papers* 2011; 65, 6: 822-828.
27. Horvath AE, Lindström T. *Nordic Pulp and Paper Research Journal* 2007; 22, 1: 87-92.
28. Sjöström E. *Nordic Pulp and Paper Research Journal* 1989; 4, 2: 90-93.
29. Lindström T. *Nordic Pulp and Paper Research Journal* 1992; 7, 4: 181-192.
30. Barzyk D, Page DH, Ragauskas A. *Journal of Pulp and Paper Science* 1997; 23, 2: J59-J61.
31. Laine J, Lindström T. *Das Papier* 2001; 1: 40-45.
32. Laine J, Lindström T, Glad-Nordmark G, Risinger G. *Nordic Pulp and Paper Research Journal* 2002; 17, 1: 50-56.
33. Fält S. *Model Studies of Cellulose Fibers and Films and Their Relation to Paper Strength*. Licentiate thesis, MidSweden University, Stockholm, 2003.
34. Baranski A, Dziembaj R, Konieczna-Molenda A, Lagan JM, Walas S. *Polish Journal of Chemical Technology* 2004; 6, 1: 1-8.
35. Łojewska J, Miskowicz P, Łojewska T, Proniewicz LM. *Polymer Degradation and Stability* 2005; 88, 3: 512-520.
36. Zou X, Gurnagul N, Vesaka T, Bouchard J. *Polymer Degradation and Stability* 1994; 43: 393-402.
37. Zou X, Uesaka T, Gurnagul N. *Cellulose* 1996; 3, 1: 269-279.
38. Shahani CJ. *Accelerated Aging of Paper: Can It Really Foretell the Permanence of Paper*. Preservation Research and Testing Series: no. 9503. Washington, DC: Preservation Directorate, Library of Congress, 2005.
39. Shahani CJ, Harrison G. Spontaneous formation of acids in the natural aging of paper. In: *Works of Art on Paper, Books, Documents and Photographs: Techniques and Conservation*. Baltimore, 2002.
40. Scallan AM. *Tappi Journal* 1983; 66, 11: 73-75.

Received 06.11.2012 Reviewed 02.08.2013



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- surface (smoothness, roughness, degree of dusting, sizing and picking of a surface),
- absorption, permeability (air permeability, grease permeability, water absorption, oil absorption) and deformation,
- optical (brightness ISO, whiteness CIE, opacity, colour),
- tensile, bursting, tearing, and bending strength, etc.,
- compression strength of corrugated containers, vertical impact testing by dropping, horizontal impact testing, vibration testing, testing corrugated containers for signs „B” and „UN”.

#### The equipment consists:

- micrometers (thickness), tensile testing machines (Alwetron), Mullens (bursting strength), Elmendorf (tearing resistance), Bekk, Bendtsen, PPS (smoothness/roughness), Gurley, Bendtsen, Schopper (air permeance), Cobb (water absorbiveness), etc.,
- crush tester (RCT, CMT, CCT, ECT, FCT), SCT, Taber and Lorentzen&Wettre (bending 2-point method) Lorentzen&Wettre (bending 4-point method and stiffness rezonanse method), Scott-Bond (internal bond strength), etc.,
- IGT (printing properties) and L&W Elrepho (optical properties), ect.,
- power-driven press, fall apparatus, incline plane tester, vibration table (specialized equipment for testing strength transport packages),
- atomic absorption spectrometer for the determination of trace element content, pH-meter, spectrophotometer UV-Vis.

#### Contact:

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