ISSN 1392 - 1207. MECHANIKA. 2006. Nr.3(59)

Research of paper/paperboard mechanical characteristics

E. Kibirkštis*, A. Kabelkaitė**
**Kaunas University of Technology, Studentų 56, 51424 Kaunas, Lithuania, E-mail: edmundas.kibirkstis@ktu.lt*
***Kaunas University of Technology, Studentų 56, 51424 Kaunas, Lithuania, E-mail: asta.kabelkaite@ktu.lt*

1. Introduction

Quality of polygraphic publications is successfully determined not only by the control of printing processes but also by the properties of materials and their mechanical characteristics.

Packages occupy a significant place in polygraphic production. Packaging materials used for printing packages have to possess proper exploitation characteristics during conveyance and long term storage under cyclic changes of temperature and humidity. Mechanical strength is one of the most significant properties of paper. Packaging materials have to meet the elevated mechanical strength requirements. Under conventional usage conditions the paper is usually subjected to lower than fracture force. Therefore, the paper behaviour characteristics prior the fracture is of greater importance than the fixed absolute resistance to the value of fracture [1].

During exploitation package paper or paperboard, as package material, has to resist the load for a long time. For this reason, in the design of packages strength and creep strains of these materials are to be taken into consideration.

The aim of this work is to determine mechanical characteristics of both qualitative and defective paper/paperboard, and the effect of printing processes (varnishing, one-side and two-side printing) on mechanical characteristics of the mentioned polygraphic materials.

The mechanism of paper break-down is analysed in papers [2-4]. A paper band tears off subjected to external tensile force *F*. Each paper fiber is subjected to the applied load. The works [5] say that in the first stage the interfiber links rupture takes place because of tension up to the visible paper break-down. Further on, the weakest fibres begin splitting, cracks appear and when stresses redestribute they grow up into the main crack resulting in the paper band break. Hence, weak fibres initiate the paper tear off process, thus paper break can be analysed as a chain reaction type [6].

Paper/paperboard strength dependence on varied load, moisture sorption is analysed in works [7-12], and on fibers cross-section – in work [13]. In addition, the authors study the effect of separate paper components such as fibers length, paper mass and filling composition, coated layer composition, coated layer particles size, etc. on mechanical properties of the paper [2-3, 14-16].

Differently from the above mentioned works this article analyses paper/paperboard mechanical characteristics such as fracture force, tensile stresses, fracture strains and it has defined the effect of printing processes and various defects of these materials on the mentioned mechanical properties.

2. Research methods and equipment

Tests were carried out on a tensile machine Heckert FP10/1. Samples of tested paper types were clamped in it without any degree of freedom, material itself being not tensed. Relative speed between the grips was constant – 100 mm/min. 20 specimens of one material were used: 10 in machine direction (further – MD) specimens and 10 in cross-machine direction (further – CD) specimens. Each specimen was 15 mm width and 150 mm length (Fig. 1). Paper thickness up to 200 μm was measured with an optimeter, while over 200 μm – with a mechanical micrometer. Tests were made at 24°C of ambient temperature and at 55% humidity.

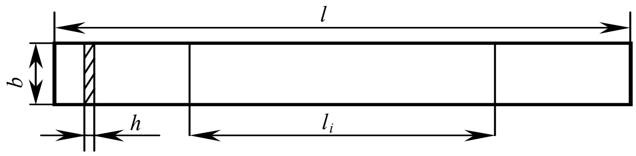

Fig. 1 Diagram of an experimental specimen for tension analysis: l is initial specimen length; l_i is initial specimen length between the grips of tensile machine (operational length); h is specimen thickness; b is specimen width

Paper strength measurements are attributed to the measurement of conditionally short-term loads which is described by two fracture mechanisms: separate fibers crack and fibers tear off from paper thickness due to the interfiber fracture forces [3]. Therefore, the paper fracture stress σ_f is expressed with the sum

$$\sigma_f = \sigma_P + \sigma_I \tag{1}$$

where σ_P is a part of paper strength depending on separate fibers resistance to crack; σ_I is a part of paper strength depending on fibers resistance to plucking from paper thickness [2, 7].

General purpose paper/paperboard types were taken for experiments. Side by side high quality paper and that containing various defects were also used. Table 1 presents the types of experimental paper and their description.

During the course of testing ultimate tensile force at break of a specimen and paper elongation prior its break were determined. The specimens thickness was also measured. According to the obtained data tensile stresses at break were calculated [4, 17]

$$\sigma = F/A \tag{2}$$

where σ is tensile stresses, MPa; F is tensile force, N; A is area of a specimen under tension, mm^2.

In addition, strain at fracture was also calculated [4,17]

$$\varepsilon_f = (\Delta l / l_i) \times 100 \quad (3)$$

where ε_f is fracture strain, %; Δl is elongation of a specimen before fracture.

3. Analysis of research data

The obtained research data are presented in Tables 2 - 5, and according to them the stresses dependences on strains of each material are drawn (Fig. 2 - 5).

It is seen in Fig. 2 that in machine direction non-defective paper (curve *1m*) is stronger than defected

Table 1

Types of paper used for experiments

Specimen No.	Paper/ print on paper	Grammage, g/m^2	Description
1	Offset paper Plano Plus	80	Offset, woodfree paper (no defects)
2	Print on Plano Plus paper	80	Rough, unevenly inked paper surface
3	Print on Plano Plus paper	80	Rough, unevenly inked paper surface (second specimen)
4	Offset paper Plano Plus with uneven surface	80	Offset, woodfree uneven structure paper
5	Paperboard Multicolor Mirabell	250	One-side coated paperboard with a grey other side (no defects)
6	Print on Multicolor Mirabell paperboard	250	White dots visible on the solid plate of an image
7	Multicolor Mirabell paper board with surface layer defects	250	After printing white fibres obtained on the solid plate of an image
8	Paperboard Nikoprint	230	One--side coated scrap paperboard with a grey other side (no defects)
9	Print on Nikoprint paperboard	230	Breakaway of coated layer
10	Nikoprint paperboard with coated layer defects	230	After printing broken away coated layer
11	Coated paper Luxo Satin	300	Semimat, heavier coated, white, woodfree paper (no defects)
12	Print on Luxo Satin paper	300	Uneven paper surface
13	Paperboard Kromopak	250	One-side coated woodfree paperboard with a white other side (no defects)
14	Print on Kromopak paperboard	250	Breakaway of coated layer
15	Coated paper Luxo Satin	200	Semimat, heavier coated, white woodfree paper (no defects)
16	Print on Luxo Satin paper	200	One-side print without defects
17	Print on Luxo Satin paper	200	Two-side print without defects
18	Coated paper Luxo Satin	130	Semimat, heavier coated, white, woodfree paper (no defects)
19	Print on Luxo Satin paper	130	One-side print without defects
20	Print on Luxo Satin paper	130	Two-side print without defects
21	Print on Luxo Satin paper	130	One-side print coated with varnish layer

Table 2

Tensile tests results of Plano Plus paper (80 g/m^2)

Specimen marking	Paper specimen description	Thickness h, mm	Cross-section area A, mm^2	Elongation before fracture Δl, mm	Fracture force F_B, N	Fracture stress σ_f, MPa	Fracture strain ε_f, %
1m	Paper without defects (MD)	0.089	1.335	2.79	92.0	68.9	2.79
1c	Paper without defects (CD)	0.089	1.335	4.06	26.4	19.8	4.06
2m	Paper with unevenly inked surface (MD)	0.093	1.389	2.83	85.2	61.3	2.83
2c	Paper with unevenly inked surface (CD)	0.093	1.389	5.54	29.7	21.4	5.54
3m	Paper with unevenly inked surface, second specimen (MD)	0.112	1.680	2.51	97.5	58.1	2.51
3c	Paper with unevenly inked surface second specimen (CD)	0.112	1.680	4.78	36.1	21.5	4.78
4m	Paper of uneven structure without an ink layer (MD)	0.112	1.680	2.40	95.1	56.6	2.40
4c	Paper of uneven structure without an ink layer (CD)	0.112	1.680	4.83	35.7	21.3	4.83

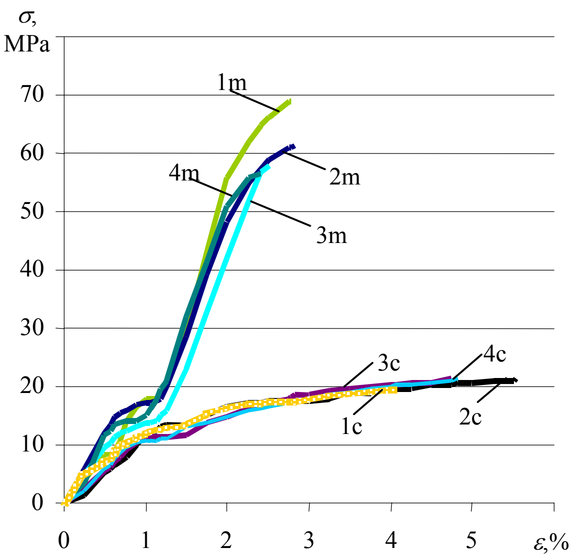

Fig. 2 Stresses dependence on strain of Plano Plus paper: *1m* - paper without defects (MD); *1c* - paper without defects (CD); *2m* - paper with unevenly inked surface (MD); *2c* - paper with unevenly inked surface (CD); *3m* - paper with unevenly inked surface, second specimen (MD); *3c* - paper with unevenly inked surface, second specimen (CD) *4m* - paper of uneven structure without an ink layer (MD); *4c* - paper of uneven structure without an ink layer (CD)

specimens, its fracture stress is 68.9 MPa, and its strain– 2.79%. The fracture stress in machine direction defected paper (curves *2m, 3m, 4m*) is lower ($\sigma_{f(2m)}$=61.3 MPa, $\sigma_{f(3m)}$=58.1 MPa, $\sigma_{f(4m)}$=56.6 MPa). The fracture strain of defected paper with an ink layer (curve *2m*) is 1.4% greater than that of standard paper ($\varepsilon_{f(2m)}$=2.83%), the fracture strain of defected paper with an ink layer of a second specimen (curve *3m*) is $\varepsilon_{f(3m)}$=2.51%, while that of defected paper without an ink layer is $\varepsilon_{f(4m)}$=2.40%.

The fracture stress in cross machine direction nondefected paper (curve *1c*) is $\sigma_{f(1c)}$=19.8 MPa, while that of defected paper with an ink layer (curves *2c, 3c*) and without an ink layer (curve *4c*) is greater ($\sigma_{f(2c)}$=21.4 MPa, $\sigma_{f(3c)}$=21.5 MPa, $\sigma_{f(4c)}$=21.3 MPa, respectively). Similarly, the fracture strains in cross machine direction specimens show alike tendency: fracture strain of nondefected paper (curve *1c*) is $\varepsilon_{f(1c)}$=4.06%, that of defected paper with an ink layer (curves *2c, 3c*) and without an ink layer (curve *4c*) is also greater ($\varepsilon_{f(2c)}$=5.54%, $\varepsilon_{f(3c)}$=4.78%, $\varepsilon_{f(4c)}$=4.83%, respectively).

Standard Multicolor Mirabell type paperboard was used side by side paperboard of that type with coated layer faults (i.e. appearance of white fluffs on a coated

Table 3

Tensile tests results of Multicolor Mirabell paperboard (250 g/m^2)

Specimen marking	Paper specimen description	Thickness h, mm	Cross-section area A, mm^2	Elongation before fracture Δl, mm	Fracture force F_B, N	Fracture stress σ_f, MPa	Fracture strain ε_f, %
5m	Paperboard without defects (MD)	0.321	4.815	3.08	228.0	47.4	3.08
5c	Paperboard without defects (CD)	0.321	4.815	5.10	87.6	18.2	5.10
6m	Paperboard with coated layer faults after inking an ink layer (MD)	0.328	4.920	2.55	216.0	43.9	2.55
6c	Paperboard with coated layer faults after inking an ink layer (CD)	0.328	4.920	4.52	85.3	17.3	4.52
7m	Paperboard with coated layer faults, without print (MD)	0.320	4.800	2.55	214.2	44.6	2.55
7c	Paperboard with coated layer faults, without print (CD)	0.320	4.800	4.40	88.3	18.4	4.40

Table 4

Tensile tests results of Nikoprint paperboard (230 g/m^2)

Specimen marking	Paper specimen description	Thickness h, mm	Cross-section area A, mm^2	Elongation before fracture Δl, mm	Fracture force F_B, N	Fracture stress σ_f, MPa	Fracture strain ε_f, %
8m	Paperboard without defects (MD)	0.255	3.825	2.59	190.9	49.9	2.59
8c	Paperboard without defects (CD)	0.255	3.825	4.64	53.6	14.0	4.64
9m	Paperboard with coated layer faults after inking ink layer (MD)	0.263	3.945	2.93	185.0	46.9	2.93
9c	Paperboard with coated layer faults after inking ink layer (CD)	0.263	3.945	5.30	49.7	12.6	5.30
10m	Paperboard with coated layer faults, without print (MD)	0.264	3.960	2.90	191.3	48.3	2.90
10c	Paperboard with coated layer faults, without print (CD)	0.264	3.960	5.25	52.4	13.2	5.25

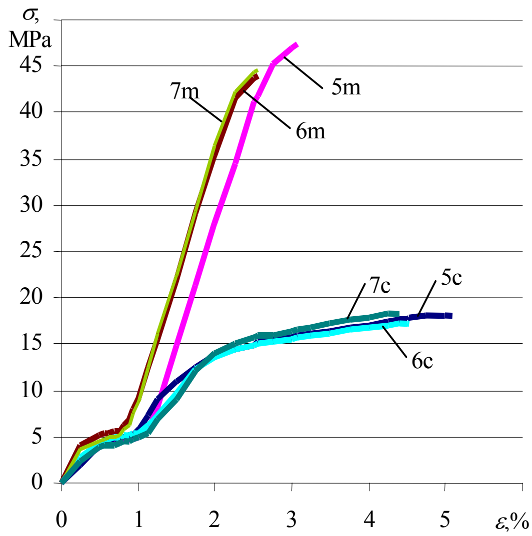

Fig. 3 Stresses dependence on strain of Multicolor Mirabell type paperboard: *5m* - paperboard without defects (MD); *5c* - paperboard without defects (CD); *6m* - paperboard with coated layer faults after inking an ink layer (MD); *6c* - paperboard with coated layer faults after inking an ink layer (CD); *7m* - paperboard with coated layer faults, without print (MD); *7c* - paperboard with coated layer faults, without print (CD)

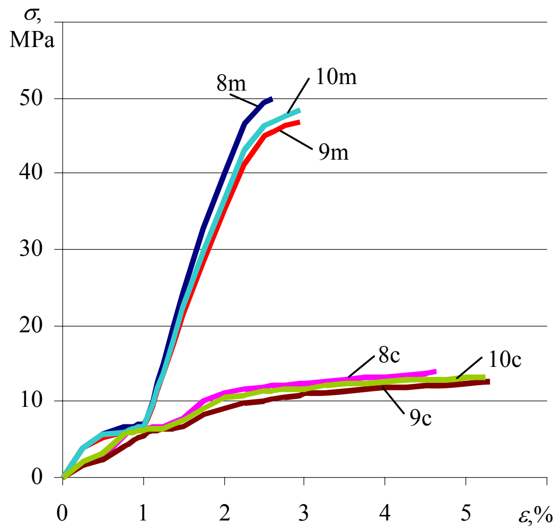

Fig. 4 Nikoprint type paperboard (230 g/m^2) stresses dependence on strain: *8m* - paperboard without defects (MD); *8c* - paperboard without defects (CD); *9m* - paperboard with coated layer faults after inking ink layer (MD); *9c* - paperboard with coated layer faults after inking ink layer (CD); *10m* - paperboard with coated layer faults, without print (MD); *10c* - paperboard with coated layer faults, without print (CD)

layer while printing). Fig. 3 illustrates that nondefected paperboard (MD) (curve *5m*) is more resistant to tear-off (fracture stress $\sigma_{f(5m)}$=47.4 MPa), and fracture strain $\varepsilon_{f(5m)}$=3.08% is also greater than that of defected paperboard specimens. Whereas, in defected paperboard with one-side print (curve *6m*) and defected paperboard without print (curve *7m*) fracture strain is $\varepsilon_{f(6m)}=\varepsilon_{f(7m)}$=2.55%, and fracture stress is $\sigma_{f(6m)}$=43.9 MPa, $\sigma_{f(7m)}$=44.6 MPa, respectively.

Fracture strain in cross machine direction nondefected paperboard (curve *5c*) is $\varepsilon_{f(5c)}$=5.10%, while that of paperboard with coated layer faults after inking an ink layer (curve *6c*) and without print (curve *7c*) is $\varepsilon_{f(6c)}$=4.52%, $\varepsilon_{f(7c)}$=4.40%, respectively. Meanwhile, fracture stresses of all these specimens are similar, i.e. $\sigma_{f(5c)}$=18.2 MPa, $\sigma_{f(6c)}$=17.3 MPa, $\sigma_{f(7c)}$=18.4 MPa, respectively.

The tensile test results of both standard Nikoprint paperboard and paperboard with coated layer faults (i.e. breakaway of coated layer from the paper base) are presented in Fig. 4.

It is evident that fracture stress of Nikoprint type paperboard (MD) (curve *8m*) is greater and is $\sigma_{f(8m)}$=49.9 MPa, whereas fracture stress of paperboard with a broken away coated layer after print (curve *9m*) is $\sigma_{f(9m)}$=48.3 MPa and fracture stress of paperboard with a broken away coated layer prior print (curve *10m*) is $\sigma_{f(10m)}$=48.3 MPa. Fracture strain of nondefected (MD) (curve *8m*) is 2.59% and of defected paperboard with one side print (curve *9m*) and of defected one prior inking (MD) (curve *10m*) is $\varepsilon_{f(9m)}$=2.93% and $\varepsilon_{f(10m)}$=2.90%, respectively.

Fracture stress of Nikoprint paperboard (CD) (curve *8c*) is $\sigma_{f(8c)}$=14.0 MPa, and that of this type paperboard with a broken away coated layer after inking (curve *9c*) and without ink (curve *10c*) is a little less, i.e. $\sigma_{f(9c)}$=12.6 MPa and $\sigma_{f(10c)}$=13.2 MPa, respectively. Fracture strain in cross machine direction is greater of paperboard with a broken away coated layer (curves *9c, 10c*), it reaches $\varepsilon_{f(9c)}$=5.30%, $\varepsilon_{f(10c)}$=5.25%, respectively, and that of standard paperboard (curve *8c*) is $\varepsilon_{f(8c)}$=4.64%.

Table 5

Tensile tests results of Luxo Satin coated paper (300 g/m^2)

Specimen marking	Paper specimen description	Thickness h, mm	Cross-section area A, mm^2	Elongation before fracture Δl, mm	Fracture force F_B, N	Fracture stress σ_f, MPa	Fracture strain ε_f, %
11m	Coated paper without defects (MD)	0.270	4.05	2.70	183.1	45.2	2.70
11c	Coated paper without defects CD)	0.270	4.05	4.75	112.1	27.7	4.75
12m	Coated paper with unevenly inked on its surface (MD)	0.256	3.90	3.00	162.6	41.7	3.00
12c	Coated paper with unevenly inked on its surface (CD)	0.256	3.90	5.11	100.5	25.8	5.11

Table 6

Tensile tests results of Krompak paperboard (250 g/m^2)

Speci-men mark-ing	Paper specimen description	Thick-ness h, mm	Cross-section area A, mm^2	Elongation before fracture Δl , mm	Frac-ture force F_B, N	Fracture stress σ_f, MPa	Frac-ture strain ε_f, %
13m	Paperboard without defects (MD)	0.321	4.815	2.56	197.3	40.98	2.56
13c	Paperboard without defects (CD)	0.321	4.815	4.94	80.15	16.65	4.94
14m	Paperboard with coated layer faults after inking an ink and varnish layer (MD)	0.349	5.235	2.25	163.9	31.30	2.25
14c	Paperboard with coated layer faults after inking an ink and varnish layer (CD)	0.349	5.235	4.25	79.6	15.21	4.25

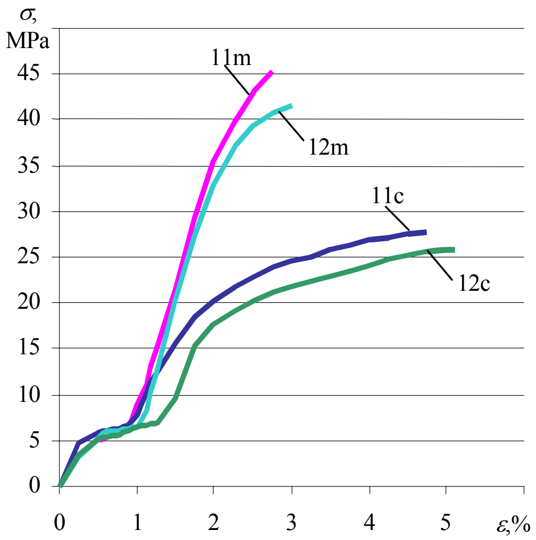

Fig. 5 Coated Luxo Satin type paper (300 g/m^2) stresses dependence on strain: *11m* - coated paper without defects (MD); *11c* - coated paper without defects (CD); *12m* - coated paper with unevenly inked surface (MD); *12c* - coated paper with unevenly inked surface, (CD)

Standard Luxo Satin type coated paper and its defected specimens having uneven coated layers after inking were employed for tests. Fig. 5 indicates that fracture stress of nondefected coated paper (MD) (curve *11m*) is $\sigma_{f(11m)}$=45.2 MPa, whereas paper with uneven coated layer (curve *12m*) fractural down at stress 41.7 MPa. Fracture stress of standard Luxo Satin type coated paper (MD) (curve *11m*) is $\varepsilon_{f(11m)}$=2.70% while that of defected coated paper (MD) (curve *12m*) is $\varepsilon_{f(12m)}$=3.00%.

Fracture stress of standard Luxo Satin coated paper (CD) (curve *11c*) is 27.7 MPa, while that of this type paper with uneven coated surface (curve *12c*) is $\sigma_{f(12c)}$=25.8 MPa. Fracture strain of standard Luxo Satin type coated paper (CD) (curve *11c*) is 4.75%, while that of defected paper (curve *12c*) is 5.11%.

Both paperboards without defects and that with a broken away coated layer were used for tests after inking and varnish (see Fig. 6).

The obtained results indicate that the strength of standard Krompak type paperboard (MD) (curve *13m*) is greater, its fracture stress is $\sigma_{f(13m)}$=40.98 MPa, while fracture stress of paperboard with a broken away coated layer after print (curve *14m*) is $\sigma_{f(14m)}$=31.30 MPa Fracture strain of nondefected paperboard (MD) (curve *13m*) is 2.56%, and that of defected paperboard with print (MD) (curve *14m*) is $\varepsilon_{f(14m)}$=2.25%.

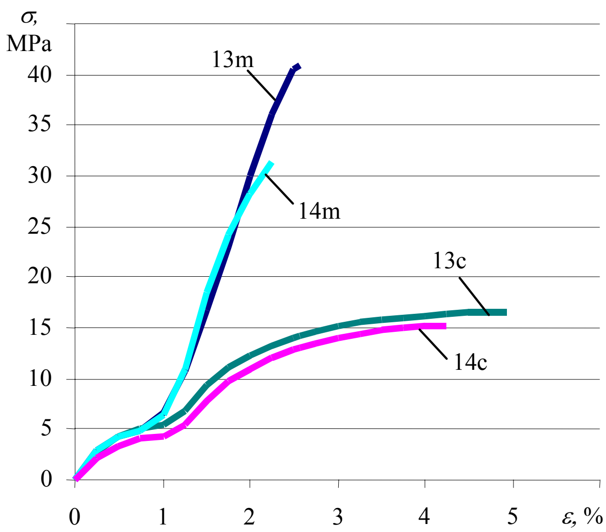

Fig. 6 Krompok type paperboard (250 g/m^2) stresses dependence on strain: *13m* - paperboard without defects (MD); *13c* - paperboard without defects (CD); *14m* - paperboard with a broken away coated layer after inking and varnish layers (MD); *14c* - paperboard with a broken away coated layer after inking and varnish layers (CD)

Fracture stress of standard Krompak type paperboard (CD) (curve *13c*) is 16.65 MPa, while that of this type paperboard with a broken away layer after printing (curve *14c*) is $\sigma_{f(14c)}$= 15.21 MPa. Fracture strain of standard Krompak type paperboard (CD) (curve *13c*) is 4.75%, and that of defected paperboard (curve *14c*) is 5.11%.

Tests have been carried out for comparing the quality paper specimens with defective ones by inking on one or both sides. These tests are intended to find out the effect of one-side, two-side prints Sand one-side varnishing on tensile stresses characteristics. The obtained results are presented in Tables 7-8, and Figs. 7-8.

Fig. 7 illustrates the dependence of coated Luxo Satin type paper stresses on strain. Quality paper and one-side and two-side prints on it were used for experiments.

The obtained results reveal that the stresses of both standard Luxo Satin coated paper (MD) (curve *15m*) and one-side print (MD) (curve *16m*) are nearly equal

Table 7

Tensile tests results of Luxo Satin coated paper (200 g/m^2)

Specimen marking	Paper specimen description	Thickness h, mm	Cross-section area A, mm^2	Elongation before fracture Δl, mm	Fracture force F_B, N	Fracture stress σ_f, MPa	Fracture strain ε_f, %
15m	Paperboard without defects (MD)	0.184	2.760	2.93	159.0	57.60	2.93
15c	Paperboard without defects (CD)	0.184	2.760	4.58	79.80	28.90	4.58
16m	Paperboard without defect with one-side print (MD)	0.185	2.775	2.88	158.1	56.97	2.88
16c	Paperboard without defects with one-side print (CD)	0.185	2.775	4.58	79.70	28.72	4.58
17m	Paperboard without defects with two-side print (MD)	0.185	2.780	2.65	153.9	55.40	2.65
17c	Paperboard without defects with two-side print (CD)	0.185	2.780	4.45	79.64	28.63	4.45

Table 8

Tensile tests results of Luxo Satin paper (130 g/m^2)

Specimen marking	Paper specimen description	Thickness h, mm	Cross-section area A, mm^2	Elongation before fracture Δl, mm	Fracture force F_B, N	Fracture stress σ_f, MPa	Fracture strain ε_f, %
18m	Coated paper without defects (MD)	0.098	1.470	2.65	111.7	76.0	2.65
18c	Coated paper without defects (CD)	0.098	1.470	4.65	43.60	29.7	4.65
19m	Coated paper without defects with one-side print (MD)	0.099	1.485	2.65	112.0	75.4	2.65
19c	Coated paper without defects with one-side print (CD)	0.099	1.485	4.35	45.50	30.7	4.35
20m	Coated paper without defects with two-side print (MD)	0.100	1.500	2.63	111.3	74.2	2.63
20c	Coated paper without defects with two-side print (CD)	0.100	1.500	4.35	43.25	28.9	4.35
21m	Coated paper without defects with one side print and a varnish layer (MD)	0.099	1.485	2.65	111.7	75.2	2.65
21c	Coated paper without defects with one-side print and a varnish layer (CD)	0.099	1.485	4.45	44.89	30.2	4.45

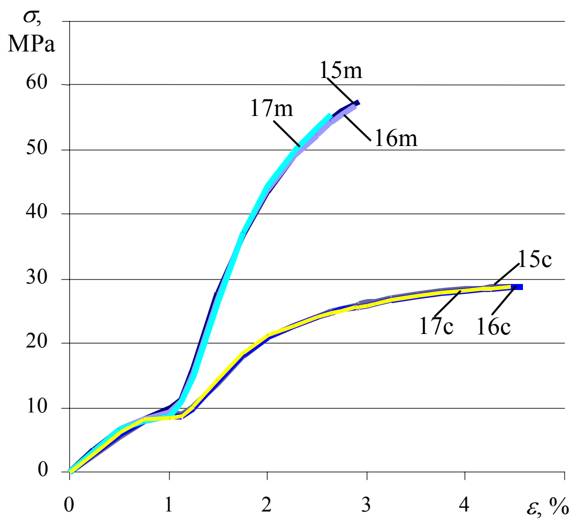

Fig. 7 Dependence of Luxo Satin type coated paper (200 g/m^2) stresses on strain: *15m* - coated paper (MD); *15c* - coated paper (CD); *16m* - coated paper with one-side print (MD); *16c* - coated paper with one-side print (CD); *17m* - coated paper with two-side print (MD); *17c* - coated paper with two-side print (CD)

(fracture stresses are $\sigma_{f(15m)}$=57.60 MPa, $\sigma_{f(16m)}$=56.97 MPa, respectively, while fracture strains are $\varepsilon_{f(15m)}$=2.93%, $\varepsilon_{f(16m)}$=2.88%, respectively). The fracture stresses of two-side print (curve *17m*) decrease to 3.8 % when printed on both sides ($\sigma_{f(17m)}$ = 55.40 MPa), and the fracture strain declines to $\varepsilon_{f(17m)}$=2.65%.

Stresses of standard Luxo Satin coated paper (CD) (curve *15c*), for one-side print (curve *16c*) and two-side print (curve *17c*) are nearly the same (fracture stresses are $\sigma_{f(15c)}$=28.90 MPa, $\sigma_{f(16c)}$=28,72 MPa, $\sigma_{f(17c)}$=28.63 MPa, respectively). Whereas fracture strains of Luxo Satin paper (curve *15c*) and one-side print (curve *16 c*) are the same $\varepsilon_{f(15c)} = \varepsilon_{f(16c)}$=4.58%) while that of two-side print (curve *17c*) is $\varepsilon_{f(17c)}$=4.45%.

Standard Luxo Satin type coated paper (130 g/m) and the same quality paper with an ink layer on one side, with an ink layer print on both sides and an one-side print coated with a varnish layer have been used for tests. The obtained results are given in Fig. 8.

These results demonstrate that fracture stresses and fracture strains of standard Luxo Satin coated paper (MD) (curve *18m*), one-side print (curve *19m*), two-side print (curve *20m*) and one-side varnish coated print (curve *21m*) are nearly the same ($\sigma_{f(18m)}$=76.00 MPa, $\sigma_{f(19m)}$=75.40 MPa, $\sigma_{f(20m)}$=75.20 MPa, $\sigma_{f(21m)}$=74.20 MPa, $\varepsilon_{f(18m)} = \varepsilon_{f(19m)} = \varepsilon_{f(21m)}$=2.65%, $\varepsilon_{f(20m)}$=2.63%, respectively), while ink and varnish layer has almost no noticeable effect on paper and print strength characteristics.

Fracture stresses of standard Luxo Satin coated paper (CD) (curve *18c*), one-side print (curve *19c*), two-side print (curve *20c*) and one-side print coated with a varnish layer (curve *21c*) are nearly the same: $\sigma_{f(18c)}$=29.70 MPa, $\sigma_{f(19c)}$=30.70 MPa, $\sigma_{f(20c)}$=28.90 MPa, $\sigma_{f(21c)}$=30.20 MPa, respectively. Whereas, fracture strains of one-side print (curve *19c*), two-side print (curve *20c*) and one-side print coated with varnish (curve *21c*) are about 5% smaller

($\varepsilon_{f(19c)}$=4.35%, $\varepsilon_{f(20c)}$=4.35%, $\varepsilon_{f(21c)}$=4.45%) than the paper fracture strain ($\varepsilon_{f(18c)}$=4.65%).

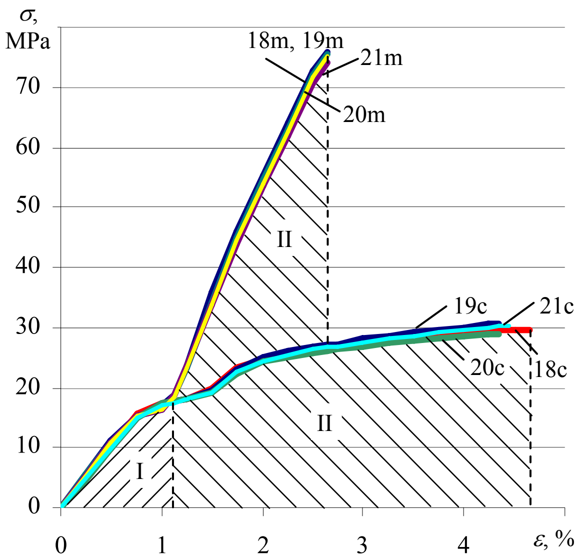

Fig. 8 Dependence of Luxo Satin type coated paper (130 g/m^2) stresses on strain: *18m* - coated paper (MD); *18c* - coated paper (CD); *19m* - coated paper with one-side print (MD); *19c* - coated paper with one-side print (CD); *20m* - coated paper with two-side print (MD); *20c* - coated paper with two-side print, (CD); *21m* - coated paper with one-side print and a varnish layer (MD); *21s* - coated paper with one-side print and a varnish layer (CD). Zone I - in which paper/paperboard casting direction has negligible effect on the strains and stresses values, Zone II - in which paper/paperboard casting direction has considerable effect on the above mentioned characteristics

Having analysed the variation of the obtained strains and stresses dependences (curves) (Figs. 2-8) it should be emphasized that the variation law of these dependences is similar. For this reason it is expedient to separate two typical zones (Fig. 8): zone I- here paper/paperboard casting direction has negligible effect on the values of strains and stresses, and zone II – here paper/paperboard casting direction has a great effect on the above mentioned mechanical characteristics.

Having analysed the research data it is possible to draw the following conclusions.

4. Conclusions

1. The variation character of paper strain dependences on stresses makes it possible to separate two zones, namely, zone I in which paper casting direction has a negligible effect on paper/paperboard mechanical characteristics (strains and stresses), and zone II in which casting direction has a great effect on the aforementioned characteristics.

2. In cross machine direction of paper/paperboard fairly small stresses cause substantial strains in the mentioned materials.

3. Uneven structure in machine direction offset Plano Plus type (80 g/m^2) paper reduces the paper fracture stress, while in cross machine direction this unevenness affects the fracture strain, i.e. fracture strain of the defected paper without an ink film and with it is greater than that of quality paper.

4. The defects of a coated layer of Multicolor Mirabell type (250 g/m^2) paperboard (i.e. white fibres appearance on a coated layer when printing) reduce fracture stress and fracture strain in machine direction. In cross machine direction stresses at break are nearly the same, whereas fracture strain decreases.

5. Due to a broken away coated layer of Nikoprint type (230 g/m^2) paperboard fracture stress in machine direction decreases, whereas in cross machine direction it is almost the same. In this case fracture strains in machine and cross machine directions increase.

6. Luxo Satin type paper (300 g/m^2) with an uneven surface coated layer has smaller fracture stresses, while its fracture strains are greater.

7. Due to the broken away coated layer of Kromopak type paperboard (250 g/m^2) after inking and varnish spraying both fracture stresses and fracture strains decrease in machine and cross machine directions.

8. Fracture stresses and fracture strains hardly vary in machine direction after spraying an ink layer on one side or two sides of a q uality paper sheet. Due to ink and varnish spray the fracture strains may decrease up to 6% in cross machine direction while the fracture stresses remain fairly similar.

9. In design of packages, which in practice are subjected to small loads, paper/paperboard casting direction may be not taken into consideration as the strains caused by stresses slightly differ because of paper/paperboard casting direction (see zone I). When packages are subjected to greater stresses, paper/paperboard casting directions have a significant effect on mechanical characteristics of the mentioned materials, therefore it is to be considered in design (see zone II).

Research was performed in pursuance of project: Bilateral Lithuanian-Ukrainian international project of research and experimental development programme N004SMM567/3 „Development of new technologies and printing materials for printed production, its qualitative evaluation, standardization and identification“

References

1. **Flate, D.** Properties of Paper.- Moscow: Wood industry, 1986.-680 p. (in Russian).
2. **Levshina, V.V., Byvshev, A.V.** Structure and strength of paper sheet.-Chemistry of Vegetative Stock, 1999, No 2, p.135-141 (in Russian).
3. **Levshina, V.V., Byvshev, A.V.** Formation of structural-mechanical properties of paper.-Chemistry of Vegetative Stock, 1999, No2, p.143-148 (in Russian).
4. Handbook of Physical Testing of Paper. - New York: Marcel Dekker, Inc., 2002, t.2, v.1 edited by Richard E. Mark. - v.2 edited by Jens Borch.
5. **Bergman, J., Rennel, J.** The relation between fider strength. -Svensk Papperstidn, 1967, v.70, No22, p.757-771.
6. **Leopold, B**. Effect of pulp processing on individual fiber strength.- Tappi, 1965, v.48, No 5, p.298-303.
7. **Alfthan, J**. The effect of humidity cycle amplitude on accelerated tensile creep of paper.- Mechanics of Time-Dependet Materials.- Kluwer Academic Publishers,

2004, v.8, p.289-302.
8. **Lif, J. O., Östlund, S., Fellers, C**. Applicability viscoelasticity of paper at small deformations.- Mechanics of Time-Dependet Materials.- Kluwer Academic Publishers, 1998, v.2, No3, p.245-267.
9. **Larotonda, F. D. S., Matsui, K. S., Paes, S. S., Laurindo, J. B.** Impregnation of kraft paper with cassava-starch acetate - analysis of the tensile strength, water absorption and water vapor permeability.- Starch/Stärke, 2003, v.55, p.504-510.
10. **Beldie, L., Sandberg, G., Sandberg, L.** Paperboard packages exposed to static loads-finite element modelling and experiments.- Packaging Technology and Science.- John Wiley&Sons, 2001, v.14, p.171-178.
11. **Sørensen, G., Hoffmann, J.** Moisture sorption in moulded fibre trays and effect on static compression strength.- Packaging Technology and Science.- John Wiley&Sons, 2003, v.16, p.159-169.
12. **Henry, W., Haslach, J.** The moisture and rate-dependent mechanical properties of paper.- Mechanics of Time-Dependet Materials, 2000, v. 4, No 3, p.169-210.
13. **Eichhorn, S. J., Sirichaisit, J., Young, R. J.** Deformation mechanisms in cellulose fibres, paper and wood.- Materials Science.- Springer Science, 2004, No36, p.3129-3135.
14. **Morsy, F. A., El-Sherbiny, S**. Mechanical properties of coated paper: influence of coating properties and pigment blends.- Materials Science.- Springer Science, 2004, v.39, p.7327-7332.
15. **Sahoo, P. K., Swain, S. K., Debsarkar, N. L.** Preparation, characterization, and properties of unbleached, bleached, and grafted pulps from JRC-321 variety jute fiber.- Applied Polymer Science.- John Wiley&Sons.- 2002, v.83, p.1963-1969.
16. **Krook, M., Gällstedt, M., Hedenqvist, M. S.** A study on montmorillonite/polyethylene nanocomposite extrusion-coated paperboard.- Packaging Technology and Science.- John Wiley&Sons, 2005, v.18, p.11-20.
17. EN 12625-4:1999. Tissue paper and tissue products. Determination of tensile strength, stretch at break and tensile energy absorption. 9 p.

E. Kibirkštis, A. Kabelkaitė

POPIERIAUS/KARTONO MECHANINIŲ CHARAKTERISTIKŲ TYRIMAS

R e z i u m ė

Straipsnyje nagrinėjamos popieriaus ir kartono mechaninės charakteristikos (trūkimo jėga, tempimo įtempiai, trūkio deformacijos), taip pat spaudos procesų (lakavimo, vienpusės ir dvipusės spaudos) bei įvairių paviršiaus defektų įtaka šių poligrafinių medžiagų mechaninėms charakteristikoms.

Tyrimų rezultatai parodė, kad gautas popieriaus deformacijų priklausomybių nuo įtempių kitimo pobūdis, leidžia išskirti dvi zonas: zoną, kurioje popieriaus liejimo kryptis turi nedidelę įtaką popieriaus ir kartono mechaninėms charakteristikoms (deformacijoms ir įtempiams), ir zoną, kurioje liejimo kryptis turi didelę įtaką šioms charakteristikoms. Nustatyta, kad vienpusė ir dvipusė spauda, bei lakavimas įtempimo charakteristikoms žymesnės įtakos neturi. Popieriaus ir kartono paviršiaus netolygumas, kreidinio sluoksnio atsisluoksniavimas, spausdinimo metu kreidinio sluoksnio paviršiuje atsirandantys plaušeliai turi nedidelę įtaką trūkimo jėgos ir deformacijos vertėms.

E. Kibirkštis, A. Kabelkaitė

RESEARCH OF PAPER/PAPERBOARD MECHANICAL CHARACTERISTICS

S u m m a r y

This article deals with paper/paperboard mechanical characteristics (fracture force, stresses and strains), printing processes (varnishing, two-side print) and the effect of various surface defects on mechanical properties of aforementioned materials.

The research results have indicated that the obtained variation character of strain dependences on stresses makes it possible to distinguish two zones: the first -where the paper casting direction slightly affects paper/paperboard mechanical characteristics (strains and stresses), and the second zone - where the casting direction has a significant effect on the above-mentioned characteristics. One-side and two-side prints as well as varnishing are found to have a negligible effect on tension characteristics. Uneven paper/paperboard surface, breaking away of a coated layer during printing, and the appearance of fibers on a coated layer affect greatly the values of fracture stresses and strains.

Э. Кибиркштис, А. Кабелкайте,

ИССЛЕДОВАНИЕ МЕХАНИЧЕСКИХ ХАРАКТЕРИСТИК БУМАГИ/КАРТОНА

Р е з ю м е

В данной статье были исследованы механические характеристики (разрушающие силы, напряжение и деформации при растяжении) бумаги/картона, а также влияние процессов печати (односторонней и двухсторонней печати, лакировки) и различных дефектов поверхности на механические характеристики упомянутых полиграфических материалов.

Результаты исследований показали, что характер полученных зависимостей деформации бумаги/картона от величины напряжении позволяет выделить две зоны: область, в которой направление образцов имеет незначительное влияние на механичес-кие характеристики (деформации и напряжения) бумаги/картона, и зону, в которой направление образцов имеет большое влияние на упомянутые характеристики. Установлено, что односторонняя и двухсторонняя печать, а также лакировка не имеет значительного влияния на механические характеристики полиграфических материалов. Неравномерности поверхности бумаги/картона, отслоение мелованного слоя, появившиеся волокна на поверхности мелованного слоя в процессе печати имеют значительное влияние на значение разрушающую силу и деформацию.

Received December 21, 2005