ISSN 1392 - 1207. MECHANIKA. 2008. Nr.1(69)

Investigation of tension of flock printing materials

O. Mizyuk*, E. Kibirkštis, S. Petraitiene*****
Ukrainian Academy of Printing, Podgolosko st. 19, 79020 Lvov, Ukraine, E-mail: mizyuk@mail.ru
***Kaunas University of Technology, Studentų 56, 51424 Kaunas, Lithuania, E-mail: edmundas.kibirkstis@ktu.lt*
****Kaunas University of Technology, Studentų 50, 51368 Kaunas, Lithuania, E-mail: stase.petraitiene@ktu.lt*

1. Introduction

A wide range of packaging materials used in making different packages demands a comprehensive analysis of their physical-mechanical and operational properties. A significant place in the packaging market is taken by polymeric packaging. The authors of [1] have studied the mechanical properties of polymer films LDPE used in producing flexible packages. Dependences and curves of stresses versus strains have been presented and the stress values of flow, fracture and strains have been determined. Paper [2] deals with the results of experimental investigations of mechanical breakdown of individual polymers in mixtures with other polymers depending on different factors of mechanical treatment, polymer and mixture properties. Researchers [3] have analyzed the effect of test speed and temperature on the essential work of fracture tearing experiments of PET film.

In order to find new approaches to the formation of structural-mechanical properties of paper materials, researchers have worked out a theoretical background for paper strength [4]. In their work they have applied the methodologies that give a possibility to evaluate not only strength, length, diameter of the fibres, but also paper cohesion (bonding strength of a single fibre in a sheet), as well as fibre orientation in it. As a result, a mathematical description of the fracture force in dependence upon the force of fracture and pulling out a separate fibre has been worked out and approbated.

Certain papers have analyzed stress-strain and elastic-plastic behaviour of paper materials in performing printing, folding, calendering, cutting operations [5], which is of great importance in making packaging production and in printing-publishing industry; paperboard deformation properties before and after creasing [6]; effect of humidity on paper/paperboard properties [7, 8], which is important in making packages from paper materials.

Stress-strain behaviour of paperboard in tension and compression is analyzed in [9], an appropriate correspondence between the experimentally determined and theoretically calculated bending moment has been obtained. The causes of fracture propagation in paperboard have been defined with the help of a scanning electronic microscope. The authors of [10] have studied the bending moment of resistance M_{max} in bending and its original angle depending on stress σ .

In work [11] paper/paperboard mechanical characteristics, such as fracture force, tensile stresses, fracture strains have been analysed, and the effect of printing processes and various defects of these materials on the mentioned mechanical properties have been defined.

Paper tension tests are discussed in [12]. For experimental purposes, the authors were using paper made from bleached conifer and deciduous cellulose. In addition, as mentioned by the researchers, the paper tension tests also served as an indicator of paper aging quality. In paper [13] have analysed monotonic and low cycle tension compression and pure bending characteristics of specimens with electromechanically hardened surface. The authors [14] suggested method for durability estimation through the mechanical properties in tension.

At present flock printing materials, consisting of paperboard and flock fixed on a glue film (Fig. 1), have been successfully used in making attractive souvenir packaging. Since studies of the mentioned materials are scarce, there is a need for investigating the impact of their properties on mechanical characteristics.

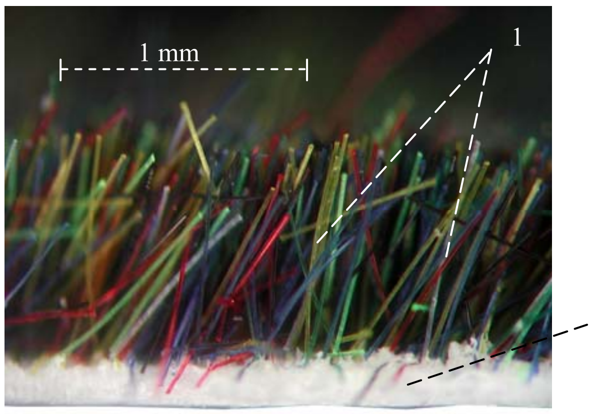

Fig. 1 Microphotography of a flock printing material (view of a section): *1* – flock; *2* – paperboard

In previous paper [15] has been performed investigation of mechanical strength of adhesive joints of packages made from flock printing materials. The aim of our present work is to test the tension of flock printing materials and to compare the test results with the results of tension test on the paperboard without flock coating, as well as to obtain correlation curves based on experimental data.

2. Research methods and equipment

The experimental tension tests on paperboard and flock printing materials were carried out on an experimental stand with special computer software used for processing and presenting the measurement data. Samples of test paper types were clamped in it without any degree of freedom, material itself being not deformed. Speed between the grips was constant – 0.07 mm/s and 0.35 mm/s. 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 of 15 mm width and 150 mm length (Fig. 2). Paperboard thickness was measured by the indicator-type thickness calliper with precision of 0.01 mm. All specimens were conditioned and tested under standard atmospheric conditions (23°C, 50% relative humidity).

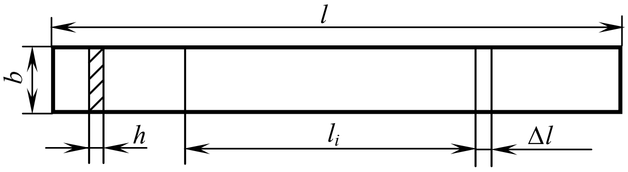

Fig. 2 Specimen for tension analysis: l is the initial specimen length; l_i is the initial specimen length between the grips of the tensile machine (operational length); h is the specimen thickness; b is the specimen width; Δl is the elongation of a specimen before fracture

Failure of the paper strip takes place under the action of applied tension force F. The process of paper failure may be considered as a chain reaction where initially the bonds between the fibres are broken under the impact of tension, and later the weakest fibres start breaking.

For experimental purposes, paperboards Arktika GC-1 with grammage of 275 and 450 g/m^2 were chosen (Table 1), as well as flock printing materials with 0.5 and 1.0 mm length polyamide flock applied on the same paperboards (linear density 3.3 dtex), which are the most widely spread.

During the course of testing, ultimate tensile force at the specimen failure and paper elongation prior to its failure were determined. The specimen thickness was also measured. According to the obtained data, tensile stresses at the fracture were calculated

$$\sigma = F/A \tag{1}$$

where σ is tensile stress, MPa; F is tensile force, N; A is the area of a specimen cross-section, mm^2.

The value of strain ε_f is determined by the relation

$$\varepsilon_f = \left(\Delta l / l_i\right) \times 100 \tag{2}$$

where Δl is the elongation of a specimen before fracture; the length of specimen l_i, fixed between two clamps of the device is 100 mm [11]. The module of longitudinal elasticity (Young's modulus) is calculated by the formula

$$E = \sigma_{pr} / \varepsilon_{pr} \tag{3}$$

The experimental data of the tension test were processed by using MathCad Professional 2003 software and applying the method of statistical analysis of the minimum squares.

3. Analysis of research data

The results of the paperboard tension tests are presented in Figs. 3, 5, while those of flock printing materials – in Figs. 4, 6.

Mechanical strength of paper materials is characterized by such indicators as resistance to fracture and strain. The indicator of strain of the paperboard before fracture, expressed in percent, characterizes the strength of the paperboard better than the value of the force needed for fracture it. The stretching properties of the paperboard are extremely important for packaging materials. Higher stretching ability of the paperboard helps to redistribute stresses and prevent their dangerous concentration in particular places.

Table 1

Tension tests results of paperboard and flock printing material specimen

Specimen marking	Paper specimen description	Grammage, g/m^2	Thickness h, mm	Cross-section area A, mm^2	Elongation at fracture Δl, mm	Fracture force F_f, N	Fracture stress σ_f, MPa	Fracture strain ε_f, %	Young's modulus E, MPa	Relation of ε_f in cross-machine direction and ε_f in machine direction
1	2	3	4	5	6	7	8	9	10	11
Tension velocity 0.35 mm/s										
1m	Arktika GC-1 paperboard (MD)	450	0.72	10.8	2.80	288.47	26.71	2.80	9.18	2.25
1c	Arktika GC-1 paperboard (CD)	450	0.72	10.8	6.30	191.96	17.77	6.30	3.38	
2m	Arktika GC-1 paperboard (MD)	275	0.41	6.15	3.15	269.55	43.83	3.15	13.43	2.22
2c	Arktika GC-1 paperboard (CD)	275	0.41	6.15	7.0	210.95	34.30	7.0	6.13	
3m	Arktika GC-1 paperboard (MD), flock length of 0.5 mm	450	0.72	10.8	3.5	333.35	30.87	3.5	9.15	1.7
3c	Arktika GC-1 paperboard (CD), flock length of 0.5 mm	450	0.72	10.8	5.95	150.12	13.90	5.95	3.44	
4m	Arktika GC-1 paperboard (MD), flock length of 0.5 mm	275	0.41	6.15	3.50	301.79	49.07	3.50	15.65	1.9

Continues of Table 1

1	2	3	4	5	6	7	8	9	10	11
4c	Arktika GC-1 paper-board (CD), flock length of 0.5 mm	275	0.41	6.15	6.65	150.25	24.43	6.65	6.38	
5m	Arktika GC-1 paper-board (MD), flock length of 1.0 mm	275	0.41	6.15	3.15	300.64	48.88	3.15	15.52	1.89
5c	Arktika GC-1 paper-board (CD), flock length of 1.0 mm	275	0.41	6.15	5.95	133.83	21.76	5.95	5.88	
Tension velocity 0.07 mm/s										
1m	Arktika GC-1 paper-board (MD)	450	0.72	10.8	2.94	283.72	26.27	2.94	9.02	2.19
1c	Arktika GC-1 paper-board (CD)	450	0.72	10.8	6.44	189.84	17.58	6.44	3.14	
2m	Arktika GC-1 paper-board (MD)	275	0.41	6.15	3.22	267.77	43.54	3.22	13.05	2.2
2c	Arktika GC-1 paper-board (CD)	275	0.41	6.15	7.07	208.73	33.94	7.07	6.07	
3m	Arktika GC-1 paper-board (MD), flock length of 0.5 mm	450	0.72	10.8	3.43	305.75	28.31	3.43	8.25	1.76
3c	Arktika GC-1 paper-board (CD), flock length of 0.5 mm	450	0.72	10.8	6.02	143.53	13.29	6.02	3.27	
4m	Arktika GC-1 paper-board (MD), flock length of 0.5 mm	275	0.41	6.15	3.36	288.62	46.93	3.36	13.97	2.0
4c	Arktika GC-1 paper-board (CD), flock length of 0.5 mm	275	0.41	6.15	6.72	147.12	23.92	6.72	6.23	
5m	Arktika GC-1 paper-board (MD), flock length of 1.0 mm	275	0.41	6.15	3.29	289.23	47.03	3.29	14.64	1.81
5c	Arktika GC-1 paper-board (CD), flock length of 1.0 mm	275	0.41	6.15	5.95	133.45	21.70	5.95	5.69	

The fracture of paperboard can relatively be divided into two stages: during the first, slow failure of inter-fibre bonds without the failure of fibres is taking place in the specimen under tension, while during the second, fast failure of fibres and bonds along the end fracture zone of the paper material occurs.

Total paperboard strains under the effect of applied force is known to consist of elastic strain, which is characterized by the changes in inter-molecular distances in the structure of the paper material; retarded elastic, under which the configuration of fibre macromolecules and the distance between inter-bonded molecules on the fibre surface are changing; plastic, under which fibres are shifted irreversibly and molecular bonds between adjoining surfaces are broken. Therefore, under the action of increasing load on the specimen, first it behaves as an elastic body, and following Hooke's law, the initial part of the curve is a straight line (Fig. 3). If the application of load is stopped, the strip of paperboard/flock printing material will regain its initial qualities and will compress to zero elongation. In other words, elastic strain appears and disappears momentarily (Fig. 4, zone *I*). Further, plastic properties of paper material appear, consequently, the linear dependence between stress and strain changes into a curve (Fig. 3, curve *2c*). The point on the border between the initial straight line and the curved zone of the graph characterizes the limit of elasticity of the specimen. The point on the X-coordinate axis corresponds the strain to the limit of elasticity, and on the Y-axis – the stress to the limit of elasticity.

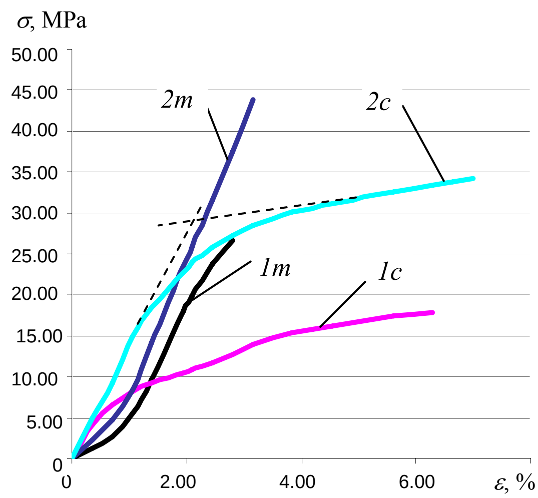

Fig. 3 Dependence between stress and strain of paperboard Arktika GC-1 specimens at tension velocity 0.35 mm/s: *1m* – paperboard Arktika 450 g/m^2 (MD); *1c* – paperboard Arktika 450 g/m^2 (CD); *2m* – paperboard Arktika 275 g/m^2 (MD); *2c* – paperboard Arktika 275 g/m^2 (CD)

The load exceeding elasticity limit leads to retarded elastic strain (Fig. 4, zone *II*), which gradually increases and completely disappears after the load is removed. Further increase in the applied load leads to plastic strain (Fig. 4, zone *III*). As the picture shows, the curved area of the graph later changes into a linear one again, which then continues up to the fracture moment of the paperboard/flock printing material.

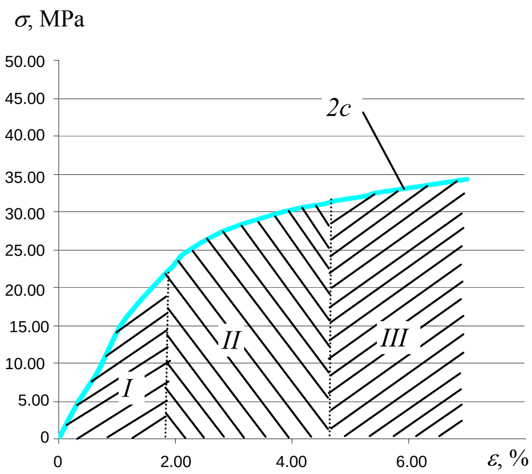

Fig. 4 Distribution of total strain of paperboard Arktika 275 g/m^2 (CD) specimen under tension at the velocity of 0.35 mm/s: *I* – zone of elastic strain; *II* – zone of retarded elastic strain; *III* – zone of plastic strain

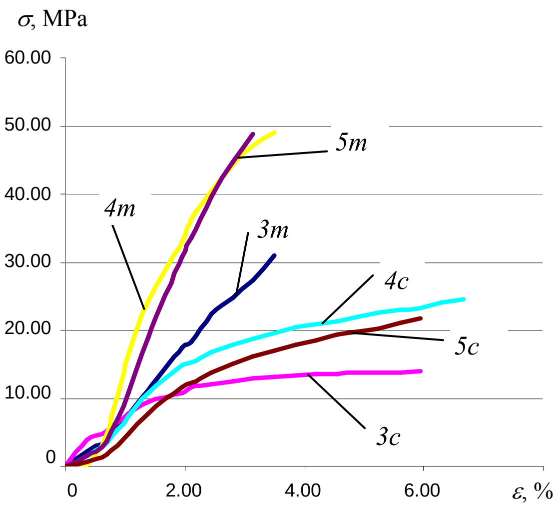

Fig. 5 Dependence between stress and strain for specimens of flock printing materials at tension velocity 0.35 mm/s: *3m* – Arktika paperboard 450 g/m^2 (MD) and flock length of 0.5 mm; *3c* – Arktika paperboard 450 g/m^2 (CD) and flock length of 0.5 mm; *4m* – Arktika paperboard 275 g/m^2 (MD) and flock length of 0.5 mm; *4c* – Arktika paperboard 275 g/m^2 (CD) and flock length of 0.5 mm; *5m* – Arktika paperboard 275 g/m^2 (MD) and flock length of 1.0 mm; *5c* – Arktika paperboard 275 g/m^2 (CD) and flock length of 1.0 mm

During the tension tests of paperboards (Figs. 3, 6) and flock printing materials (Figs. 5, 7) in the machine direction, an increase in stress and a decrease in strain has been observed, while in the cross-machine direction – a decrease in stress and an increase in strain. The strain of paperboards Arktika 450 g/m^2 and Arktika 275 g/m^2 without flock-coating (at the specimen tension velocity 0.35 mm/s) in the cross-machine direction increases by 2.25 and 2.22 times, respectively. Strain of the same paperboards at tension velocity of 0.07 mm/s is 2.19 and 2.2 times higher than that in the machine direction. Flock printing materials at tension velocity of 0.35 mm/s in the cross-machine direction *3c, 4c* and *5c* specimens get elongated by 1.7, 1.9 and 1.89 times more, respectively, than in the machine direction. At tension velocity 0.07 mm/s, elongation of specimens *3c, 4c* and *5c* in the cross-machine direction is 1.76, 2.0 and 1.81 times higher, respectively, than that in the machine direction. The mean value of the strain of paperboards without flock coating in the machine direction decreases by 2.22 times, while that of flock printing materials – 1.84 times.

Unlike strain, stress in the machine direction increases, and for paperboards Arktika 450 g/m^2 and Arktika 275 g/m^2 without flock coating at tension velocity 0.35 mm/s (Fig. 3, specimens *1m, 2m*) it is $\sigma_{f(1m)}$= = 26.71 MPa and $\sigma_{f(2m)}$=43.83 MPa. In the cross-machine direction the stress in these paperboards is: $\sigma_{f(1c)}$=17.77 MPa and $\sigma_{f(2c)}$=34.30 MPa. The relation between the stress in the machine and cross-machine direction at the specimen tension velocity of 0.35 mm/s and 0.07 mm/s is the same, and in the case of paperboard Arktika 450 g/m^2 is 1.5:1, while for paperboard Arktika 275 g/m^2 without flock-coating it is 1.28:1. For flock printing materials, the relation of stress in the machine and cross-machine direction is as follows: specimens *3m:3c*=2.22:1, *4m:4c*=2:1, *5m:5c*=2.25:1 (at the tension velocity 0.35 mm/s); specimens *3m:3c*=2.13:1, *4m:4c*=1.96:1, *5m:5c*=2.17:1 (at the tension velocity 0.07 mm/s). The stress at paperboard fracture without flock coating is approximately 1.4 higher in the machine direction than in the cross-machine direction, while in the case of flock printing materials it is 2.12 times higher.

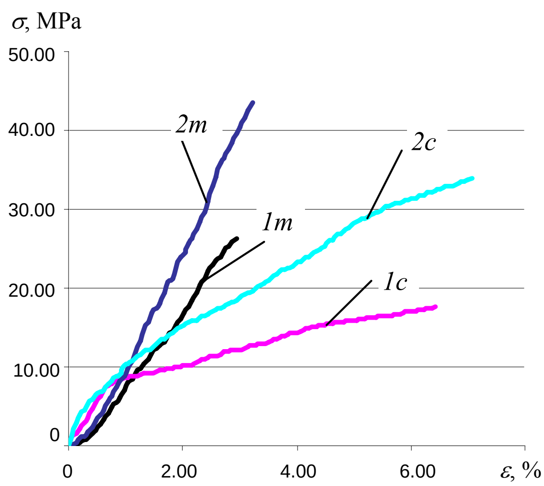

Fig. 6 Dependence between stress and strain of paperboard specimens at tension velocity 0.07 mm/s: *1m* – paperboard Arktika 450 g/m^2 (MD); *1c* – paperboard Arktika 450 g/m^2 (CD); *2m* – paperboard Arktika 275 g/m^2 (MD); *2c* – paperboard Arktika 275 g/m^2 (CD)

Higher force is needed for fracture the paperboard in the machine direction since it is used for tearing the fibres or pulling them out of the sheet thickness if the bonding strength between the fibres is lower than that of a single fibre. In the cross-machine direction the force is essentially needed for failure the bond between fibres, which strength is much lower than the fibre strength itself.

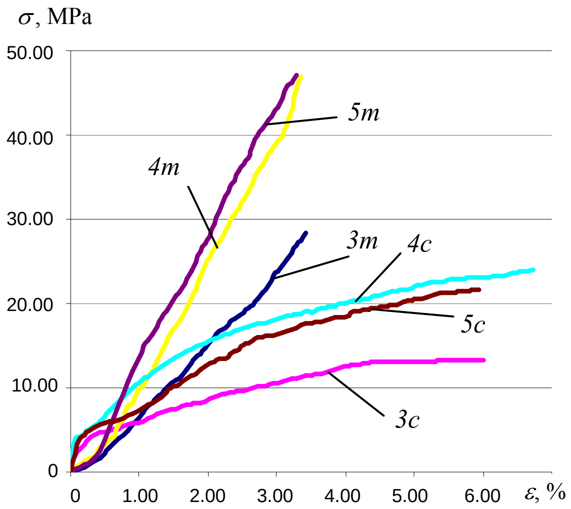

Fig. 7 Dependence between stress and strain for specimens of flock printing materials at tension velocity 0.07 mm/s: *3m* – Arktika paperboard 450 g/m^2 (MD) and flock length of 0.5 mm; *3c* – Arktika paperboard 450 g/m^2 (CD) and flock length of 0.5 mm; *4m* – Arktika paperboard 275 g/m^2 (MD) and flock length of 0.5 mm; *4c* – Arktika paperboard 275 g/m^2 (CD) and flock length of 0.5 mm; *5m* – Arktika paperboard 275 g/m^2 (MD) and flock length of 1.0 mm; *5c* – Arktika paperboard 275 g/m^2 (CD) and flock length of 1.0 mm

The performed tests have shown that velocity of the applied load has played a significant role in testing the strength of paperboard and flock printing materials in tension. When the velocity increases, the strength values of paperboard resistance to fracture go up. The faster the paperboard strip is being loaded, the higher force for rupture is needed. At tension velocity of 0.35 mm/s (Fig. 5), the required force for fracture the specimens is 0.38-13.17 N ($F_{f(5c)}$=133.83 N, $F_{f(4m)}$=301.79 N) higher than at the velocity of 0.07 mm/s ($F_{f(5c)}$=133.45 N, $F_{f(4m)}$=288.62 N) (Fig. 7), which expressed in percentage relation makes up from 0.28 to 4.36%. The lower the velocity of deformation, the lower force is needed for fracture, which may be explained by the developed flow phenomenon.

When comparing the results obtained at the velocity of 0.35 mm/s and 0.07 mm/s, it can be observed that with the increasing time of applying the load, consequently, with the decreasing velocity of tension, the load value decreases, but the material elongation increases. When the velocity of material tension is 0.07 mm/s for all specimens, except *3m* and *4m*, strain goes up to 4.76%, compared to the velocity 0.35 mm/s. The decrease strain for specimens *3m* and *4m* makes up 2.0% and 4.0% respectively. These deviations can be explained by the inhomogeneity of the paper/paperboard structure, depending on the length of fibres, their flexibility and humidity, bonding strength between fibres and technological mode of paperboard manufacturing.

Let us compare the results of tension tests of regular paperboard Arktika 275 g/m^2 (curves *2m*, *2c*, Fig. 3) and those of the flock printing material with 0.5 mm length polyamide flock fixed on the same paperboard (curves *4m*, *4c*, Fig. 5) and 1.0 mm length flock (specimens *5m*, *5c*, Fig. 5) at the tension velocity 0.35 mm/s. The stress at the fracture point for paperboard Arktika 275 g/m^2 without flock-coating is $\sigma_{f(2m)}$=43.83 MPa with strain $\varepsilon_{f(2m)}$=3.15%, $\sigma_{f(2c)}$=34.30 MPa when $\varepsilon_{f(2c)}$=7.0%; for the flock printing material with 0.5 mm length flock $\sigma_{f(4m)}$=49.07 MPa with $\varepsilon_{f(4m)}$=3.50%, $\sigma_{f(4c)}$=24.43 MPa with $\varepsilon_{f(4c)}$=6.65%; for the flock printing material with 1.0 mm length flock $\sigma_{f(5m)}$=48.88 MPa with $\varepsilon_{f(5m)}$=3.15%, $\sigma_{f(5c)}$=21.76 MPa and $\varepsilon_{f(5c)}$=5.95%. In the case of flock printing material with 0.5 mm length flock, the stress at fracture increases by 10.7% (5.24 MPa), while for the flock material with 1.0 mm length flock it increases by 10.3% (5.05 MPa), compared to the paperboard without flock-coating. The increase in resistance to fracture is related to the glue film applied when making the flock printing material: it increases the strength of paperboard surface structure to insignificant extent. Stress value at fracture the flock material with 1.0 mm length flock is even a bit lower that of the flock printing material with 0.5 mm length flock (it decreases by 0.38% in machine direction and 10.9% in cross-machine direction). As one can see, the presence of the flock and its length do not affect tension test results.

Both in the case of paperboards and flock printing materials the increase in the velocity leads to the decrease of strain and the increase of stress.

Paperboards Arktika 275 g/m^2 and 450 g/m^2 differ not only in grammage and thickness, but also in stress and strain. Stress at the fracture of paperboard Arktika 275 g/m^2 at the tension velocity 0.35 mm/s in machine direction is $\sigma_{f(2m)}$=43.83 MPa, while that of paperboard Arktika 450 g/m^2 – $\sigma_{f(1m)}$=26.71 MPa (decreases by 39%). The reason of this is the composition of the paper material, as paperboards with high grammage contain a lot of waste paper, whose fibre strength is much lower than that of cellulose fibres. Strain of the paperboard 275 g/m^2 is $\varepsilon_{f(2c)}$=7.0%, while that of Arktika 450 g/m^2 – $\varepsilon_{f(1c)}$=6.30%. The increase in strain of paperboard Arktika 275 g/m^2 is related to high flexibility of cellulose fibres and their stretching ability.

The obtained experimental data have been described by an exponential equation in which three independent coefficients *A*, *B* and *C* are calculated from the experimental data

$$\sigma_f\left(\varepsilon_f\right) = A\,exp\left(B\varepsilon_f\right) + C \qquad (5)$$

All the curves of the experimental results approximate the correlation curves well with a high indicator of correlation (Table 2, Fig. 8).

Table 2

Calculation results of statistical analysis

Tension velocity 0.07 mm/s				
No	*A*	*B*	*C*	R^2
1	2	3	4	5
1m	52.897	0.146	-54.104	0.999
1c	-16.635	-0.322	19.169	0.985
2m	61.03	0.176	62.802	0.999
2c	-54.895	-0.119	57.856	0.997
3m	72.159	0.098	-73.02	0.999

Continues of Table 2

1	2	3	4	5
3c	- 13.18	-0.365	15.203	0.994
4m	81.636	0.137	-83.396	0.999
4c	- 21.958	-0.421	24.667	0.997
5m	277.461	0.05	-279.014	0.999
5c	- 24.132	-0.297	25.982	0.997
Tension velocity 0.35 mm/s				
1m	23.348	0.292	-24.733	0.992
1c	-18.024	-0.395	19.214	0.995
2m	35.363	0.264	-36.641	0.998
2c	-35.124	-0.555	34.387	0.999
3m	-47.107	-0.344	45.539	0.995
3c	-13.96	-0.77	14.048	0.998
4m	-104.202	-0.221	99.559	0.993
4c	-27.289	-0.429	25.662	0.995
5m	117.243	0.121	-120.147	0.992
5c	-28.014	-0.312	26.185	0.994

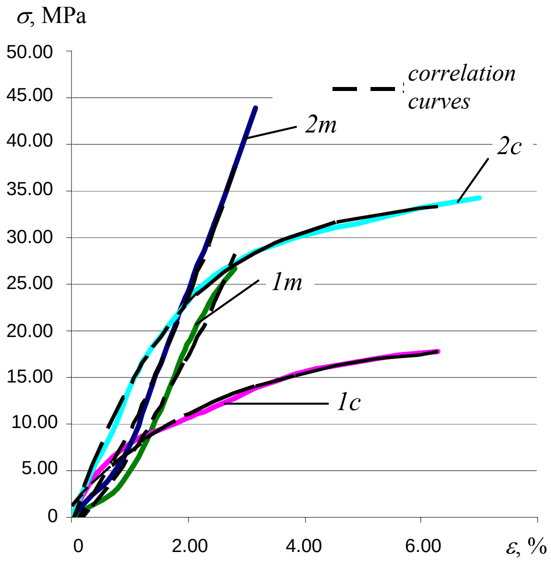

Fig. 8 Correlation curves between stress and strain for specimens of paperboard Arktika GC-1 at tension velocity 0.35 mm/s: *1m* – paperboard Arktika 450 g/m^2 (MD); *1c* – paperboard Arktika 450 g/m^2 (CD); *2m* – paperboard Arktika 275 g/m^2 (MD); *2c* – paperboard Arktika 275 g/m^2 (CD)

The correlation curves provide a possibility to obtain digital values of stress and deformation at any point.

Having analyzed the test data, we may make the following conclusions.

4. Conclusions

1. The character of strain dependence upon stress at specimen fracture has been defined. The initial part of the curve is linear as the paper strip possesses elastic properties. The point at the border between the initial straight line and the curved part of the curve characterizes elastic limit of the paperboard/flock printing material specimen. Later the curved part of the curve changes into a linear one again, which continues up to the fracture moment of the specimen.

2. An increase in stress and decrease in strain has been determined in the machine direction, while in the cross-machine direction a decrease in stress and increase in strain has been observed. Strain of paperboards without flock-coating in machine direction decrease by 2.22 times, and that of flock-coated paperboards – by 1.84 times. The stress at the fracture moment of paperboards without flock-coating is 1.4 times higher, and that of flock printing materials – 2.12 times higher in the machine direction than in cross-machine direction.

3. It has been found out that with the increasing velocity of applying loads, the paperboard resistance to fracture increase, while strain decrease. At tension velocity of 0.35 mm/s, the force of fracture of specimens increases by 0.28-4.36%, and strain decreases to 4.76%, compared to the velocity of 0.07 mm/s.

4. In comparison to paperboard without flock-coating, the stress at fracture flock printing material with 0.5 mm length flock increases by 10.7% (5.24 MPa), while in the case of 1.0 mm length flock it increases by 10.3% (5.05 MPa). The presence of the flock and its length does not affect the tension test results. The increased resistance to fracture here is related to the glue film applied in manufacturing of flock printing materials, which increases the strength of the paperboard surface structure to a certain extent.

5. It has been determined that the stress at fracture paperboard Arktika 275 g/m^2 without flock-coating at tension velocity of 0.35 mm/s in the machine direction is $\sigma_{f(2m)}$=43.83 MPa, while in the case of paperboard Arktika 450 g/m^2 – $\sigma_{f(1m)}$=26.71 MPa (decrease by 39%), that can be explained by the composition of paper material.

6. The experimental data have been described by the exponential equation with three independent coefficients. The obtained correlation curves approximate the test results well and provide a possibility to get numerical values of stress and strain at any point.

The research was performed in pursuance of the project: Bilateral Lithuanian-Ukrainian international project of research and experimental development programme V-23/2007 „Study of special printing and packaging production technologies, considering their ecological and operational qualities“. This project is supported by the Grant Foundation of Lithuanian State Science and Studies.

References

1. **Dabkevičius, A., Kibirkštis, E.** Investigation of mechanical characteristics of polimer films for packaging production. -Mechanika. -Kaunas: Technologija, 2006, No.4(60), p.5-8.
2. **Baramboim, N.K.** Some peculiarities of mechanical breakdown of components in mechanical dispersion of polymer mixtures. -J. of Applied Polymer Science, 2003, v.18, issue 9, p.2617-2621.
3. **Light, M.E., Lesser, A.J.** Effect of test conditions on the essential work of fracture in polyethylene terephthalate film. -J. of Materials Science, 2005, No.40, p.2861-2866.
4. **Levshina, V.V., Byvshev, A.V.** Structure and strength of paper sheet.-Chemistry of Vegetative Stock, 1999, No.2, p.135-141 (in Russian).
5. **Stenberg, N.** On the Out-of-Plane Mechanical Behaviour of Paper Materials. Doctoral Thesis Department of Solid Mechanics Royal Institute of Technology, Stockholm, 2002.-18p.
6. **Cavlin, S.** The unique convertibility of paperboard.

-Packaging Technology and Science, 1988, v.1, issue 2, p.77-92.
7. **Bandyopadhyay, A., Ramarao, B.V., Ramaswamy, S.** Transient moisture diffusion through paperboard materials.-Colloids and Surfaces: Physicochemical and Engineering Aspects, 2002, No.206, p.455-467.
8. **Ramarao, B.V., Chatterjee, S.G.** Moisture sorption by paper materials under varying humidity conditions. -Transaction of 11th Fundamental Research Symposium Cambridge, UK, 1997, v.2, p.703-749.
9. **Carlsson, L., Fellers, C., Ruvo, A.** The mechanism of failure in bending of paperboard. -J. of Materials Science, 1980, v.15, issue 10, p.2636-2642.
10. **Nagasawa, S., Fukuzawa, Y., Yamaguchi, T., Tsukatani, S., Katayama, I.** Effect of crease depth and crease deviation on folding deformation characteristics of coated paperboard.-J. of Materials Processing Technology, 2003, No.140, p.157-162.
11. **Kibirkstis, E., Kabelkaite, A.** Research of paper / paperboard mechanical characteristics. -Mechanika. -Kaunas: Technologija, 2006, No.3(59), p.34-41.
12. **Yamauchi, T., Tanaka, A.** Tearing test for paper using a tensile tester. -J. Wood Sci, 2002, No.48, p.532-535.
13. **Daunys, M., Sabaliauskas, A.** Influence of surface hardening on low cycle tension compression and bending characteristics. -Mechanika. -Kaunas: Technologija, 2005, No.3(53), p.12-16.
14. **Baron, A., Bakhracheva, J.** The method for lifetime estimation through the mechanical properties in tension. -Mechanika. -Kaunas: Technologija, 2004, No.3(47), p.29-32.
15. **Kibirkstis, E., Mizyuk, O.** Investigation of mechanical strength of adhesive joints of packages made from flock printing materials. -Mechanika. -Kaunas: Technologija, 2007, No.5(67), p.37-42.

O. Mizyuk, E. Kibirkštis, S. Petraitiene

MEDŽIAGŲ SU ĮKLIJUOTU PŪKU TEMPIMO TYRIMAS

R e z i u m ė

Atlikti kartono ir medžiagų su įklijuotu pūku mechaninių charakteristikų (nutrūkimo jėgos, įtempių ir deformacijų) tyrimai nutrūkimo momentu. Aprašytos deformacijos, atsirandančios medžiagoje, tempiamoje iki nutrūkimo. Nustatyta, kad išilgine popieriaus liejimo kryptimi pasireiškia popieriaus lapo įtempių padidėjimas ir deformacijos sumažėjimas, o skersine kryptimi – įtempių sumažėjimas, esant didesnei deformacijai. Gauti kartono be įklijuoto pūko įtempių ir deformacijos nutrūkimo metu tyrimo rezultatai, lyginami su rezultatais, gautais tiriant medžiagą su įklijuotu poliamidiniu pūku. Nustatyta apkrovos pridėjimo greičio įtaka nutrūkimui, tiriant kartoną ir medžiagą su įklijuotu pūku. Eksperimentinio tyrimo rezultatai aprašyti eksponentine lygtimi, gautos koreliacinės kreivės.

O. Mizyuk, E. Kibirkštis, S. Petraitiene

INVESTIGATION OF TENSION OF FLOCK PRINTING MATERIALS

S u m m a r y

Mechanical characteristics of paperboard and flock printing material (fracture force, stresses and strain) at fracture have been studied. The strain resulting in the material under tension and fracture have been described. An increase the stress and decrease the strain have been determined in the machine direction, while in the cross-machine direction stress decreases and the value of strain increases. The study results of stress and strain at fracture paperboard without flock-coating and with polyamide flock have been compared. The effect of the velocity of applying the load during tension test of the paperboard and flock printing material has been determined. The experimental results have been described by an exponential equation and correlation curves have been obtained.

О. Мизюк, Э. Кибиркштис, С. Петрайтене

ИССЛЕДОВАНИЕ ФЛОКИРОВАННЫХ МАТЕРИАЛОВ НА РАСТЯЖЕНИЕ

Р е з ю м е

Проведены исследования механических характеристик (разрушающей силы, напряжений и деформации) картона и флокированного материала при разрыве. Описаны возникающие деформаций при растяжении и разрыве материала. Установлено, что в продольном направлении листа наблюдается увеличение напряжений и уменьшение деформаций, а в поперечном направлений уменьшение напряжений при увеличении деформации. Сопоставлены результаты исследований напряжений и деформаций при разрыве картона без флок-покрытия и с нанесенным полиамидным флоком. Выявлено влияние скорости приложения нагрузки при испытании картона и флокированного материала на разрыв. Результаты экспериментов описаны экспоненциальным уравнением и получены корреляционные кривые.

Received November 07, 2007

DOI: 10.5755/j02.mech.12159