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Compressive strength of flock-coated packages

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1. Introduction

Material constants for paperboard [1-3], corrugated paperboard [4], plastic [5, 6] and composite materials [7] have been investigated and reported by many authors. The author of [1] determined the interrelation between the package geometry and shape under the effect of static and dynamic loads. Compression and tension tests showed that a cone-shaped or well-rounded package is more resistant to compression than a square or slightly rounded rectangular shape. The authors of paper [2] experimentally determined the zones of dependences between deformations and loads during compression of different grammage rectangular paperboard packages.

Static and dynamic properties, such as axial compression, flat crush, flexural performance, and radial stiffness, were established for paperboard and pultruded fiber reinforced polymer (FRP) tubes [3]. The author prove the potential benefits of hybrid tubes such as improvements in winding speeds, improvements in the amount of sheet materials hybrid tubes could hold, and whether the hybrid tubes could be reused for several production cycles.

Paper [5] studied compression strength of polysterene packages with different top and bottom part configurations. Article [6] presents experimental material of polyethylene membrane behaviour due to punch and hydro-membrane forcing through deformation. The stiffness and strength of multilayer structural elements made of carbonplastik, glass fiber of hot and cold hardening, epoxy resin are analysed [7].

Elastic-plastic deformations of anisotropic structure of paper and paperboard under compression are described by the three-dimensional model [8]. The effect of material thickness on the package deformation properties is analyzed in paper [9]. The model obtained in [10] considers the fibre length, elastic modulus and inertia moment during fibre compression. Although most of the models developed describe the compressional characteristics, they do not always provide information about variables, such as the effect of fibre interconnection, presence of pores in the paperboard and its fillers or gluing materials on the compression characteristics.

Currently there is no generally accepted methodology for predicting material properties. Most scientists when describing the stress-strain characteristics of materials used Hooke's law. An inherent weakness of this constitutive model is its limitation to the linear elastic regime of material response.

Although measurements of elastic properties of paperboard have been the subject of some studies [8, 9, 11, 12]. In literature review we found no published studies of flock-coated packages. Flock coating has found its application in textile, furniture, construction and other industries. In printing industry flock printing material is applied on paper or paperboard, and outstanding folders, business cards, diaries, notebooks, catalogues, children's books, envelopes, greeting cards or invitation cards are produced. In packaging industry flock printing material is used for gift and cosmetics packages, up-market goods, confectionery.

Therefore, the aim of the work was to study the influence of paperboard thickness and mass, the length flock and size of boxes on mechanical properties of flock-coated packages.

2. Research methods and equipment

In testing flocked package resistance to compression, a rectangular shape was chosen as it is most widely spread and is most economical in terms of the amount of packaging material and the space during storage and shipping. The dimensions of the packaging from flock printing material corresponded to those of paperboard investigated in the paper [2], so that it would be possible to compare the obtained results and determine the specific characteristics of the flocked package under compression.

The experimental compression tests of packages made from flock printing material were carried out on an experimental stand with special computer software for processing and presenting the measurements obtained, see Fig.1. Each test was repeated six times and the average was calculated and used.

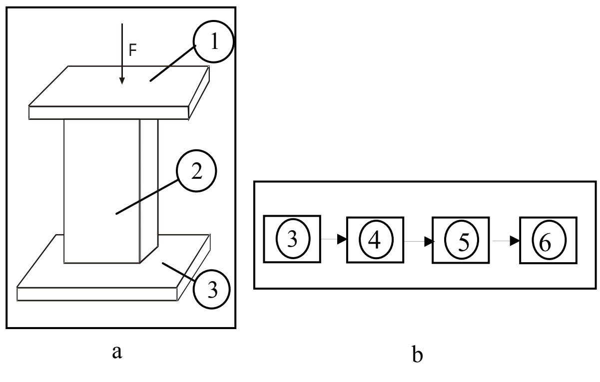


Fig. 1 Simplified scheme of package compression (*a*) and structural scheme of measuring equipment (*b*); *1* – top base slab; *2* – package under compression; *3* – bottom base slab with four wire tensosensors; *4* – tensometric amplifier TS-3; *5* – oscilloscope PicoScope 3424; *6* – computer; *F* – vertical load

During the tests, the packages *2* under investigation were placed on the bottom base slab *3* which is a part of the unit measuring the compression load acting on the package (Fig. 1). The bottom *3* and the top *1* base slabs are parallel and absolutely rigid. The mentioned slab *3* is connected with the tensoresistor measuring unit, which contains four wire tensosensors [13, 14], connected by a bridge circuit. During the package compression the sensor system signal is amplified by a tensometric amplifier TS-3 *4*. The obtained analogue signal was transmitted to oscilloscope PicoScope 3424 *5* for converting it into a digital one. The dependence of the compression force and deformations was studied on PC monitor *6*. A PC with PicoLog Recorder oscilloscope software was used for processing the obtained results and visualizing the dependences. During the test, when the bottom base slab was moving upwards vertically at a constant speed $3.5x10^{-4}$ m/s, the upper part of the package would touch the fixed top base slab, and then the compression process would start. The test data, describing the dependence of compression force upon time, when received by the computer, would be processed to determine the dependence of the compression force upon the value of the vertical package deformation.

The tests were carried out at the temperature of 20±2°C and air humidity 65± 2%.

Before measuring, the test stand was calibrated. During the calibration process it was determined that within the range of load values occurring during the tests, the dependence of computer input signal measuring the force upon the mentioned force is close to linear, and the measuring errors do not exceed ±3%.

For testing, package specimens of two sizes were used; their external view is presented in Fig. 2. The dependences of deformations upon the compression force were determined during compression tests of empty boxes.

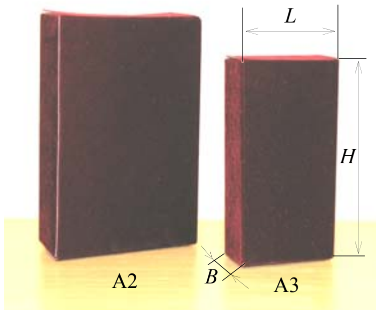


Fig. 2 Specimens (packages): A2) box size II (*H*=165 mm, *L*=118 mm, *B*=48 mm), A3) box size III (*H*=137 mm, *L*=77 mm, *B*=37 mm)

The flock printing materials used in making the packages differed in the grammage of paperboard Arktika GC-1 and the length of polyamide flock. The term 'machine direction', used in this paper, means that the paperboard direction in the side walls is parallel to the vertical axis of the package, and the term 'cross-machine direction' means that the paperboard direction in the side walls is perpendicular to the vertical axis of the package.

Table 1 presents the technical characteristics of the paperboards that were coated with flock.

Table 1

Comparison of technical characteristics of paperboards

No.	Type of paperboard	Grammage, g/m²	Thickness, µm	Stiffness, mNm					
				L&W 5° [1]			TABER 15° [2]		
				MD [3]	CD [4]	$\sqrt{MD \times CD}$	MD [3]	CD [4]	$\sqrt{MD \times CD}$
1	Arktika GC-1	275	410	37.2	18.6	26.3	20.5	10.3	14.5
2	Arktika GC-1	450	720	136.3	68.7	96.7	86.0	43.3	61.0
3	Kromopak	275	395	29.0	12.0	18.7	15.6	6.5	10.1

[1] L&W 5° – bending stiffness
[2] Taber 15° – bending moment
[3] MD – machine direction
[4] CD – cross machine direction

3. Analysis of research data

3.1. Effect of paperboard mass and thickness on its resistanse to compression

The test results of package resistance to compression are presented in Table 2.

The packages were deformed along the axis up to 40 mm that corresponds to 25 % relative strain of compression (Figs. 3-5), since the deformation of the package under compression started at 3 mm and ended at 15-20 mm, after which the compression continued with low force – 50-100 N.

Fig. 3 shows dependences of relative strain on compression stress of A2 size packages made from different grammage paperboard Arktika GC-1 and Kromopak. Boxes made of 450 g/m² paperboard Arktika in machine direction can withstand 1.42 MPa at ε=6.78 % (curve *1*, Fig. 3).

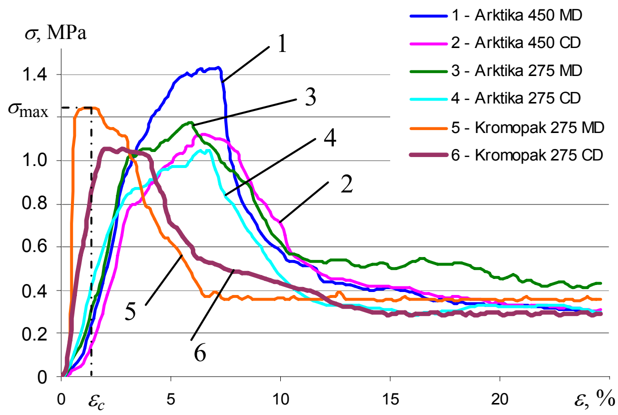


Fig. 3 Graph of resistance to compression of Size A2 boxes made of paperboard: a) *1* – Arktika 450 g/m² (MD); *2* – Arktika 450 g/m² (CD); *3* – Arktika 275 g/m² (MD); *4* – Arktika 275 g/m² (CD); *5* – Kromopak 275 g/m² (MD); *6* – Kromopak 275 g/m² (CD); σ_{max} – maximum compression stress; ε_c – relative strain at maximum compression stress

Table 2

Test results of package resistance to compression

No.	Package material: paperboard grammage and direction, dimensions of flock	Package dimensions, mm	Thickness h, mm	Cross-section area A, mm^2	Maximum compression (vertical) load F_{max}*, N	Scatter of values F_{max}, N	Deformation at maximum compression load Δ_t*, mm	Scatter of values Δ_t, mm	Stress σ_{max}*, MPa	Relative strain ε*, %
1	Arktika 450 g/m^2, MD	A2 size: H=165 mm, L=118 mm, B=48 mm	0.72	237.0	337.12	329.85÷ 342.21	11.20	11.18÷ 11.23	1.42	6.78
2	Arktika 450 g/m^2, CD		0.72	237.0	264.85	261.33÷ 268.65	10.85	10.54÷ 11.02	1.12	6.57
3	Arktika 275 g/m^2, MD		0.41	135.5	159.50	157.43÷ 161.05	9.80	9.74÷ 9.88	1.18	5.94
4	Arktika 275 g/m^2, CD		0.41	135.5	141.81	140.22÷ 143.96	11.20	11.12÷ 11.31	1.05	6.79
5	Kromopak 275 g/m^2, MD		0.395	130.5	146.6	144.0÷ 149.55	2.80	2.77÷ 2.85	1.12	1.7
6	Kromopak 275 g/m^2, CD		0.395	130.5	134.62	130.34÷ 138.92	3.50	3.47÷ 3.52	1.03	2.12
7	Arktika 450 g/m^2, MD	A3 size: H=137 mm, L=77 mm, B=37 mm	0.72	162.1	302.21	298.87÷ 304.41	4.55	4.48÷ 4.58	1.86	3.32
8	Arktika 450 g/m^2, CD		0.72	162.1	234.22	233.04÷ 235.67	7.0	6.89÷ 7.05	1.44	5.11
9	Arktika 275 g/m^2, MD		0.41	92.8	185.22	183.67÷ 186.45	5.25	5.21÷ 5.31	2.0	3.83
10	Arktika 275 g/m^2, CD		0.41	92.8	154.99	151.78÷ 156.52	6.30	6.22÷ 6.34	1.67	4.6
11	Kromopak 275 g/m^2, MD		0.395	89.4	171.65	169.81÷ 174.12	3.15	3.11÷ 3.22	1.92	2.3
12	Kromopak 275 g/m^2, CD		0.395	89.4	130.6	128.07÷ 133.15	3.50	3.43÷ 3.52	1.46	2.55
13	Arktika 450 g/m^2, MD, flock length of 0.5 mm	A2 size: H=165 mm, L=118 mm, B=48 mm	0.95	311.8	336.0	335.46÷ 336.99	8.40	8.37÷ 8.46	1.08	5.09
14	Arktika 450 g/m^2, CD, flock length of 0.5 mm		0.95	311.8	206.98	204.66÷ 207.76	8.75	8.71÷ 8.8	0.66	5.3
15	Arktika 275 g/m^2, MD, flock length of 0.5 mm		0.60	197.8	194.48	194.22÷ 195.34	7.70	7.65÷ 7.72	0.98	4.67
16	Arktika 275 g/m^2, CD, flock length of 0.5 mm		0.60	197.8	189.07	185.67÷ 191.81	7.35	7.32÷ 7.36	0.96	4.45
17	Arktika 275 g/m^2, MD, flock length of 1.0 mm		0.82	269.6	197.82	196.35÷ 198.17	8.05	8.02÷ 8.11	0.73	4.88
18	Arktika 275 g/m^2, CD, flock length of 1.0 mm		0.82	269.6	161.36	159.91÷ 162.82	12.25	12.11÷ 12.32	0.6	7.42
19	Arktika 450 g/m^2, MD, flock length of 0.5 mm	A3 size: H=137 mm, L=77 mm, B=37 mm	0.95	213.0	305.76	301.57÷ 307.86	5.95	5.88÷ 6.03	1.44	4.34
20	Arktika 450 g/m^2, CD, flock length of 0.5 mm		0.95	213.0	242.80	240.50÷ 244.35	8.40	8.35÷ 8.47	1.14	6.13
21	Arktika 275 g/m^2, MD, flock length of 0.5 mm		0.60	135.4	191.84	190.65÷ 193.31	6.65	6.54÷ 6.74	1.42	4.85
22	Arktika 275 g/m^2, CD, flock length of 0.5 mm		0.60	135.4	161.95	160.56÷ 162.72	7.0	6.94÷ 7.08	1.2	5.11
23	Arktika 275 g/m^2, MD, flock length of 1.0 mm		0.82	184.3	196.25	195.44÷ 198.83	8.05	7.97÷ 8.12	1.06	5.88
24	Arktika 275 g/m^2, CD, flock length of 1.0 mm		0.82	184.3	168.56	168.02÷ 169.36	7.70	7.63÷ 7.74	0.91	5.62

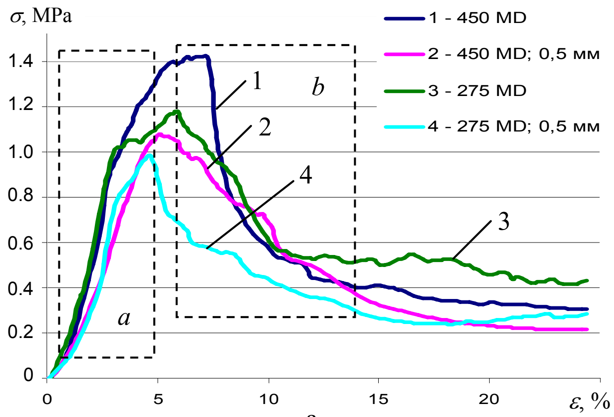
* All the values for F_{max}, σ_{max}, ε and Δ_t – are mean values from six measurements

Identical boxes made of Arktika GC-1 paperboard with the mass 275 g/m^2 in the same direction can withstand the maximum stress of 1.18 MPa at relative strain 5.94 %. This means 16.9 % less than in the first case (curve *3*, Fig. 3). The increased compression stress on paperboard are obtained by increasing its grammage and thickness (Table 1).

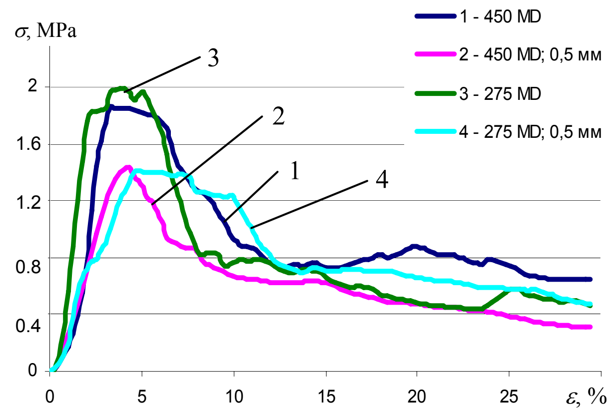
By comparing the obtained results with the previous experiments [2], we find out the maximum stress in machine direction (size A2) for different paperboards with the same mass 275 g/m^2 Kromopak – 1.12 MPa (curve *5*, Fig. 3); Arktika GC-1 – 1.18 MPa (curve *3*, Fig. 3). The difference is insignificant, however, it shows the impact of a number of variable factors on the paperboard strength: initial fibre strength and length, fibre flexibility and elasticity, adhesion strength between fibres, level and character of contexture, level of sheet density, its homogeneity, presence of non-fibrous materials. All these factors can be divided into two main groups: variable factors that are determined by the initial fibrous material and factors evoked by the technological process of manufacturing paperboard.

3.2. Size A2 and A3 package resistance to compression

Figs. 4, 5 present the dependences of resistance to compression of size A2 and A3 paperboard packages and those from flock printing material.



a

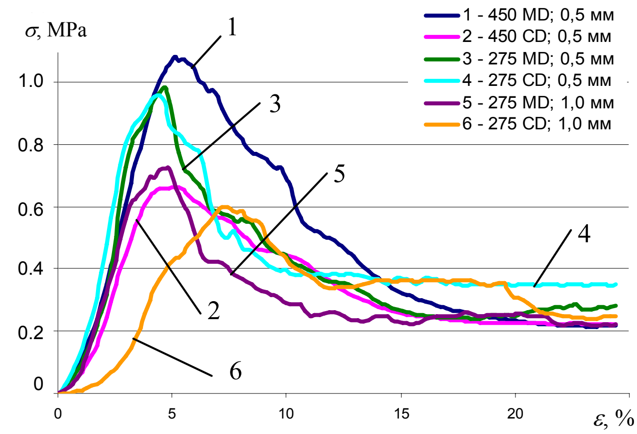


b

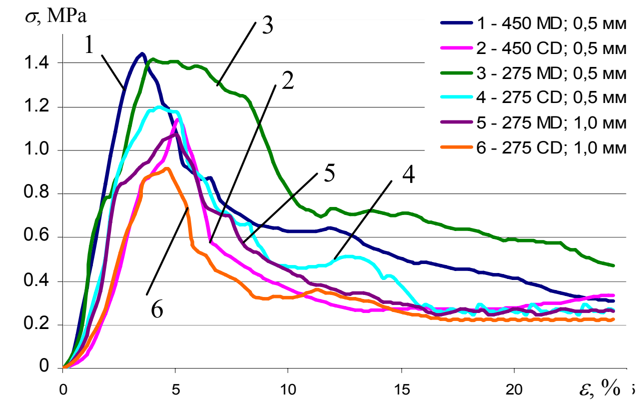
Fig. 4 Resistance to compression of boxes made of paperboard and flock printing materials of: a) A2 size boxes, b) A3 size boxes: *1* – 450 g/m^2 Arktika (MD); *2* – 450 g/m^2 Arktika (MD) and flock length of 0.5 mm; *3* – 275 g/m^2 Arktika (MD); *4* – 275 g/m^2 Arktika (MD) and flock length of 0.5 mm

When analyzing the character of changes in the curves, two zones can be distinguished (Fig. 4, a): zone a, where the dependence of compression strain on the stress is of a linear character, and zone b which is characterized by nonlinear dependence.

The stress when compressing Size A2 and A3 Arktika 450 g/m^2 paperboard (curve *1*, Fig. 4) in machine direction is 1.42 and 1.86 MPa, respectively, and in cross-machine direction it is 1.12 and 1.44 MPa; while in the case of Arktika 275 g/m^2 paperboard, MD is 1.18 and 2.0 MPa, and CD - 1.05 and 1.67 MPa. Size A3 boxes can carry a bigger load than those of Size 2. Analogically, for flock-coated packages (Fig. 5), an increase in stress is observed in Size 3 boxes: paperboard Arktika 450 g/m^2 and flock length of 0.5 mm in MD – by 0.36, in CD – by 0.48 MPa; paperboard Arktika 275 g/m^2 and flock length of 0.5 mm in MD – by 0.44, in CD – by 0.16 MPa; paperboard Arktika 275 g/m^2 and flock length of 1.0 mm in MD – by 0.33, in CD – by 0.31 MPa. The average increase in stress in percentage makes up 23.65-41 (MD) and 22.22-37.12% (CD) for paperboard package; while for flock-coated packages it is 25-31.13 (MD) and 13.3-42% (CD).



a



b

Fig. 5 Resistance to compression boxes made of flock printing materials of: a) A2 size boxes, b) A3 size boxes: *1* – 450 g/m^2 Arktika (MD) and flock length of 0.5 mm; *2* – 450 g/m^2 Arktika (CD) and flock length of 0.5 mm; *3* – 275 g/m^2 Arktika (MD) and flock length of 0.5 mm; *4* – 275 g/m^2 Arktika (CD) and flock length of 0.5 mm; *5* – 275 g/m^2 Arktika (MD) and flock length of 1.0 mm; *6* – 275 g/m^2 Arktika (CD) and flock length of 1.0 mm

The package made from Size A3 Arktika 275 g/m^2 paperboard and 0.5 and 1.0 mm length flock-coating is characterized by the following stress values: 2.0, 1.42, 1.06 MPa (MD) and 1.67, 1.12, 0.91 MPa (CD), respectively. The decrease in stress σ is caused by the increase in cross-sectional area of the flock-coated material due to the increase in the flock length; however, it does not affect the compression resistance. The difference in the maximum load for the package with 0.5-1.0 mm length flock makes up only 2 % (3.0-5.0 N).

3.3. Effect of flock length on flock-coated package resistance to compression

Research results (Fig. 5) enable us to compare the flock printing materials with different flock length in the case of paperboard 275 g/m^2 in machine direction. The compression stress on package A2 with 0.5 mm length flock (Fig. 5 a, curve *3*) is 0.98 MPa (F_{max}=194.48 N), while that with 1.0 mm length flock (Fig. 5, a, curve *5*) – 0.73 MPa (F_{max}=197.82 N). The compression stress on package A3 with 0.5 mm length flock (Fig. 5, b, curve *3*) is 1.42 MPa (F_{max}=191.84 N), while that with 1.0 mm length flock (Fig. 5, b, curve *5*) – 1.06 MPa (F_{max}=196.25 N). The stress decreases due to the increase of cross-sectional area of the flock-coated material, but the applied load F increases by 3.0-5.0 N for the flock-coated package with the 1.0 mm length flock.

Figs. 6, 7 show general view of the packages after compression. The photos demonstrate that deformation usually starts either at the top or the bottom of the side walls.

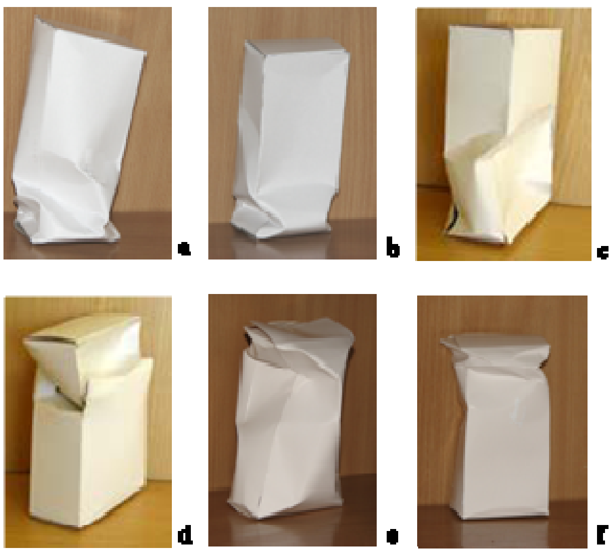


Fig. 6 General view of size A3 of paperboard packages after compression: a) Arktika GC-1 450 g/m^2 (MD); b) Arktika GC-1 450 g/m^2 (CD); c) Kromopak 275 g/m^2 (MD); d) Kromopak 275 g/m^2 (CD); e) Arktika GC-1 275 g/m^2 (MD); f) Arktika GC-1 275 g/m^2 (CD)

When compressing size A2 packages from paperboard Arktika 275 g/m^2 and 1.0 mm length flock, the package gets fractured along the adhesive joint (Fig. 7, e, f). The reason for it is the fact that while applying the load on the package, especially in machine direction, great stresses are caused, which result in fracture along the adhesive joint. Therefore, as soon as the package joint starts breaking, the compression load significantly decreases.

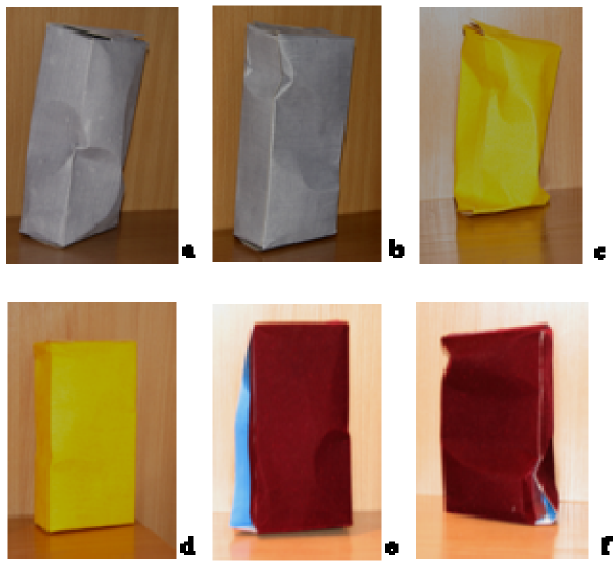


Fig. 7 General view of size A2 of flock-coated packages after compression: a) Arktika GC-1 450 g/m^2 (MD) and flock length of 0.5 mm; b) Arktika GC-1450 g/m^2 (CD) and flock length of 0.5 mm; c) Arktika GC-1 275 g/m^2 (MD) and flock length of 0.5 mm; d) Arktika GC-1 275 g/m^2 (CD) and flock length of 0.5 mm; e) Arktika GC-1 275 g/m^2 (MD) and flock length of 1.0 mm; f) Arktika GC-1 275 g/m^2 (CD) and flock length of 1.0 mm

4. Conclusions

1. Two zones have been identified: zone a, where the dependence of compression strain on the stress is of linear character and zone b where the dependence is nonlinear.

2. Size A3 boxes from paperboard and flock printing materials can carry higher compression stress than those of size A2. The stress on flock-coated size A2 package from paperboard 450 g/m^2 and 0.5 mm length flock in machine direction is 1.08 MPa, while on size A3 it is 1.44 MPa; in the case of size A2 package from paperboard 275 g/m^2 and 0.5 mm length flock in machine direction the stress is 0.98 MPa, while in size A3 – 1.42 MPa. The average increase in stress when compressing Size 3 boxes is 23.65-41 (MD) and 22.22-37.12 % (CD) for paperboard packages, while for flock-coated packages it is 25-31.13 (MD) and 13.3-42 % (CD).

3. Experimental tests with flock-coated packages from paperboard Arktika 275 g/m^2 and 0.5 and 1.0 mm length flock have shown that boxes with 1.0 mm length flock coating can increase resistance to compression by 3.0-5.0 N.

4. Special attention should be given to gluing packages with longer flock, since the application of static loads causes stresses in the package which lead to fracture along the adhesive joint.

5. The results obtained during the experimental study will help to introduce stress and relative strain during compression and determine common criteria for their loss of stability in future studies.

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PAKUOČIŲ SU ĮKLIJUOTU PŪKU ATSPARUMAS GNIUŽDYMUI

R e z i u m ė

Darbe pateikti kartono storio, masės, pūko ilgio ir pakuočių dėžučių geometrinių parametrų įtakos pakuočių su įklijuotu pūku mechaninėms charakteristikoms tyrimai. Gautos ašinės deformacijos priklausomybės nuo pakuočių gniuždymo įtempių. Analizuojant kreivių kitimo pobūdį, išskirtos dvi gniuždymo deformacijų priklausomybių nuo įtempių zonos. Nustatyta, kad pakuočių su įklijuotu pūku pasipriešinimas gniuždymui palyginti su kartono pakuotėmis, mažai padideja, nes svarbiausią reikšmę šioje srityje turi kartono savybės, t. y. tampriai plastinės kartono pluošto savybės.

E. Kibirkštis, O. Mizyuk, S. Havenko

COMPRESSIVE STRENGTH OF FLOCK-COATED PACKAGES

S u m m a r y

Study of the effect of thickness and mass of paperboard, the length of flock and size boxes on mechanical properties of flock-coated packages is presented. The dependence of relative strain on compression stress of packages has been found. While analyzing the character of the curve changes, two zones of dependence of compression strain upon stress were determined. It was found out that the package with flock coating, compared to that made from paperboard, insignificantly increases its resistance to compression, since the paperboard properties, namely, the elastic properties of the paperboard fibres, play the decisive role.

Э. Кибиркштис, О. Мизюк, С. Гавенко

ПРОЧНОСТЬ К СЖАТИЮ ФЛОКИРОВАННЫХ УПАКОВОК

Р е з ю м е

В работе представлены исследования влияния толщины и массы картона, длины флока и размера коробок на механические свойства флокированных упаковок. Получены зависимости осевой деформации от напряжения упаковок. Анализируя характер изменения кривых, выделены 2 зоны зависимости деформации сжатия от напряжения. Выявлено, что упаковка с флок-покрытием по сравнению с картонной незначительно повышает сопротивление ее к сжатию, так как решающую роль оказывают свойства картона, а именно упругопластические свойства волокон, из которых он состоит.

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