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Investigation of Structure of Flock Printing Materials at Package Gluing using Optical Microscopy

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The optical microscopy analysis was used to study the structure of paperboard and character of ripping of glued flocked samples after the break off. The effect of the filler and level of sizing on the paperboard interlayer strength, as well as resistance to bending and absorbancy ability have been studied. The tests have been performed on the number of double folds of paperboard with flocked coating and without it in machine and cross-machine direction. Different brands of paperboard, flock and gluing compositions have been analysed and recommendations for the gluing of various packaging made from flocked printing materials have been presented.

Keywords: flock printing materials, paperboard, flock, glue, sizing, filler, gluing compositions, gluing strength, paperboard delamination, optical microscopy.

INTRODUCTION

For ages, paper materials have been used for packing various goods. Present-day processing technologies give a chance to develop paper and paperboard with specific properties, which make these products extremely attractive. The present paper deals with the flocked packaging materials. The technology of electro-flocking has been successfully used for applying flock on paper materials [1, 2]. The obtained flocked material is expensive, but looks nice and can be used for packing gifts and souvenirs.

Proper selection of paperboard in terms of its properties is an essential prerequisite in obtaining the desired quality of printing or packaging production. It is well known that the properties of paper or paperboard can vary depending on the composition of the material and its finishing. By expanding and changing these factors, one can obtain qualitatively new materials. Quality indicators of paperboard can be divided into the following groups: geometrical, optical, mechanical, sorptional. All of them are closely interconnected.

Different scientists [3 – 6] have been involved in working out technologies of strengthening and determining the absorbing abilities of paper and paperboard. In papers [7 – 9] the authors have used scanning electron microscopy to study the structure of paper and paperboard, in which the fibre orientation, their type and length, as well as the presence of admixtures and pores in the paper mass can be traced. The author of [10] has used the microscopic method to study the surface of a paper band after its tear from the metal pad. In our previous paper [11] we studied the mechanical strength of glued joints of the packages made from the materials mentioned above.

For further study, we apply optical microscopy in order to explore the character of the damage occurring in the glued joints and to determine the effect of the paperboard and flock properties on the strength of gluing the packaging.

MATERIALS AND EXPERIMENTAL

The ready-made flocked materials were studied (producer "Elgraf", Ukraine), produced on paperboards: Alaska GC-2 (200 g/m^2) – cellulose paperboard based on wood pulp (thermo-mechanical cellulose) with a double-layer chalk coating on the face side and sizing on the reverse side; Duoplex UD-3 (350 g/m^2) – paperboard from 100 % wastepaper; Neoprint GD-3 (250 g/m^2) – waste-paperboard with a double-layer chalk coating on one side and addition of 10 % – 13 % cellulose, Arktika GC-1 (250 g/m^2) – cellulose paperboard based on wood pulp (thermo-mechanical cellulose) with a double-layer chalk coating on the face side and a single-layer chalk coating on the reverse side. Each of the paperboards was covered with three different kinds of flock: 0.5 mm- and 1.0 mm-length Capron flock (linear density 3.3 dtex) and 0.75 mm-length viscose flock (linear density 1.75 dtex).

12 samples of different flocked materials were glued using two kinds of glue: polyurethane two-component 1405 and water-dispersive Eukalin. 20 specimens of one material were used: 10 in machine direction (further – MD) specimens and 10 in cross-machine direction (further – CD) specimens. The load acting on the 0.012×0.15 m^2 size samples during the gluing was 2.47×10^4 N/m^2.

After tearing the glued flocked samples by Model 225-1 machine made by "Twing-Albert Instrument Company", the microscopic photos were obtained by using the optical microscope МБС-10 with EO-1312C camera (resolution 0.3 Mpxl).

The value of the paperboard capillary absorbancy was determined using the standard method [12], according to which the height of the liquid rising in the paperboard capillaries is measured during a certain time span after immersing its one end into water. The paperboard thickness was measured by the indicator-type calliper with

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resolution of 0.01 mm. The study of double-folds was carried out with the measuring gadget И-1-3 (testing rate – 120 double folds per minute; sample tension – 8 N – 10 N; measuring range – 0 – 10000 folds).

EXPERIMENTAL RESULTS AND DISCUSSION

Paperboard is known [8, 12] to consist of a number of elementary layers (Fig. 1), and we have tried to study the effect of their number and interlayer strength.

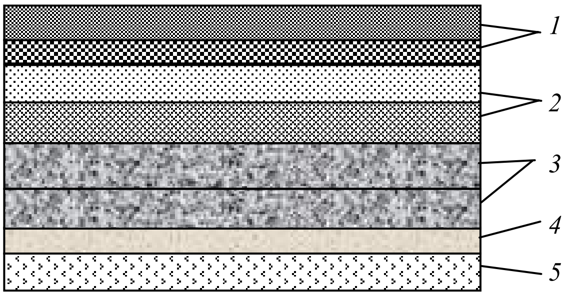


Fig. 1. Structure of elementary paperboard layers: 1 – chalk-coated layers (up to 3 layers); 2 – top layer (face side) – one or several layers of good quality raw material (bleached or unbleached cellulose, wood pulp, bleached paper waste); 3 – insert (combination of middle paperboard layers) – quite a thick layer from cheap raw material – paper waste, wood pulp, unbleached cellulose; 4 – bottom layer – one or several layers of good quality raw material; 5 – surface sizing

Fig. 2 presents a photo of flocked printing sample with flock coating on paperboard Neoprint GD-3, consisting of the top and bottom layer and an insert consisting of two layers.

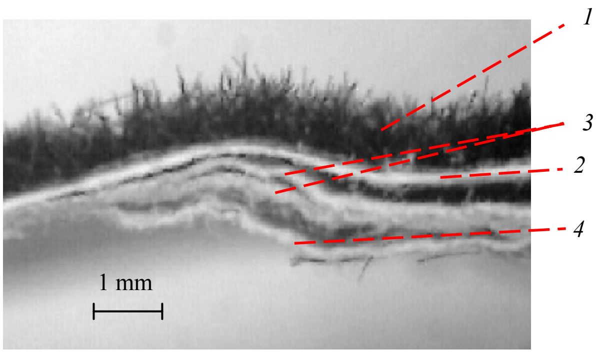


Fig. 2. Photo of the structure of a flocked printing sample: 1 – flock coating; 2 – top paperboard layer; 3 – insert; 4 – bottom paperboard layer

The experimental findings related to the thickness, density, bulk and capillary absorbency measurements of the investigated materials are presented in Table 1.

To determine the technological factors contributing to high quality packaging, we have carried out an optical microscopy study of the glued flocked samples after breaking off.

The ripping at the breaking of the flocked samples with a flock-coating on paperboards Arktika GC-1 and Alaska GC-2 occurred along the adhesive joint. Fig. 3 presents a photo of the flocked samples with a flock coating on paperboard Arktika GC-1 after breaking off. The character of rupture is analogous to one when breaking off flocked samples on paperboard Alaska GC-2. However, despite the absence of delamination in two paperboard brands, there was a difference among the various flocks.

Table 1. Paperboard characteristics

Paperboard type		Alaska GC-2	Arktika GC-1	Neoprint GD-3	Duoplex UD-3
Paperboard mass, g/m^2		200	250	250	350
Paperboard thickness, mm		0.22	0.32	0.27	0.44
Paperboard density, g/cm^3		0.909	0.781	0.926	0.795
Paperboard bulk, cm^3/g		1.1	1.28	1.08	1.25
Value of capillary absorbency, cm	MD	0.9	3.8	2.7	2.15
	CD	0.5	3.1	2.2	1.7

MD – machine direction; CD – cross machine direction.

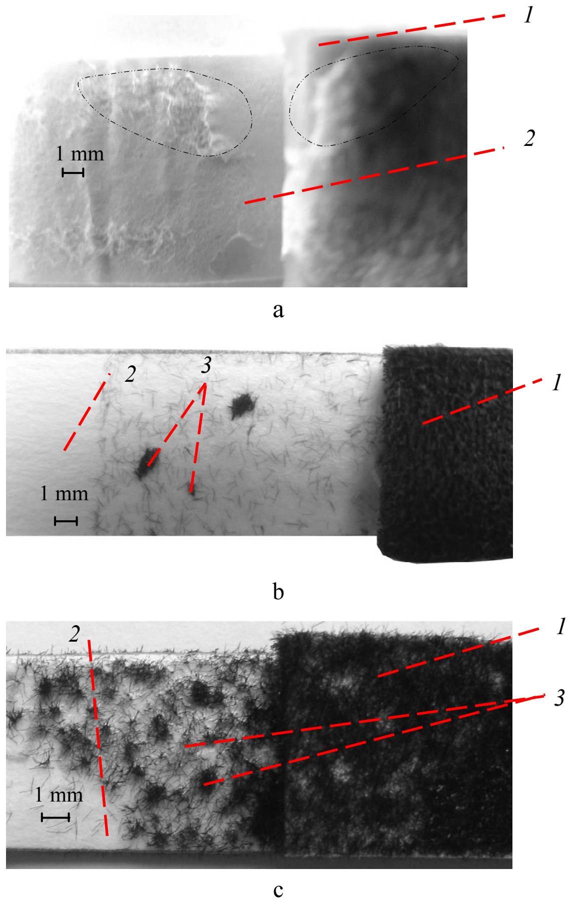


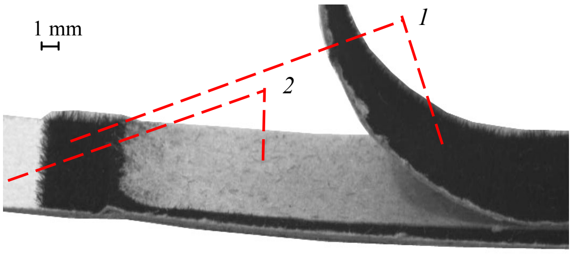
Fig. 3. Photo of the glued (glue Eukalin) flocked samples with a flock coating on paperboard: Arktika GC-1 after breaking off: a – 0.5 mm-length Capron; b – 0.75 mm-length viscose; c – 1.0 mm-length Capron: 1 – flock-coating (face side); 2 – paperboard (reverse side of flocked packaging); 3 – broken-off flock fibres

When breaking off the glued water-dispersive Eukalin glue samples from 0.5 mm-length Capron flock (Fig. 3, a), on the reverse side of the paperboard (white surface) there were no flock fibres broken loose from the face side of the flocking material. The marked area (Fig. 3, a) shows that the paperboard surface layer underwent some picking in certain places. Meanwhile, the sample from 0.75 mm-length viscose flock in Fig. 3, b shows an insignificant number of broken-off flock fibres, and a larger number of them is observed in breaking off samples from 1.0 mm-length Capron flock (Fig. 3, c).

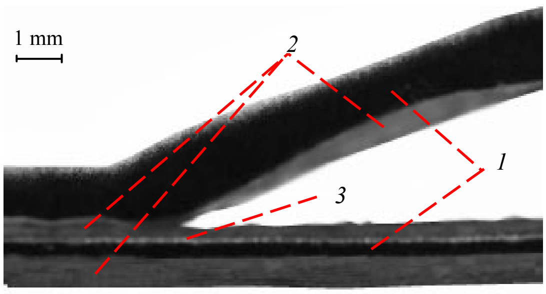
This can be explained by the length of flock fibres used in producing the flocked printing material of different rigidity. The longer the fibre, the lower is the rigidity. Longer fibres, when inserted into the glue layer, bend at the upper end and resist insertion of other fibres. The following fibres are inserted less deeply, thus their fixing strength is reduced. Consequently, with the increasing flock length, the number of unreliably glued fibres grows, and they are the first to break off 0.5 mm-length Capron flock, due to its greater rigidity, stays in a vertical position when applied in an electrostatic field, and thus reduces the number of badly glued fibres.

On the other hand, when gluing the flocked packaging, the flock gets into contact with the applied glue layer. The fibres under the load get bent and arranged quite chaotically. If the flock-glue contact area increases, the gluing strength also becomes higher. Consequently, the longer the fibre, the larger part of it gets glued to the paperboard and the harder it is to break it off. This was proved by previous tests [11], where the breaking off force for a sample from 1.0 mm-length Capron flock was 16.0 N – 26.0 N, while that from 0.5 mm-length Capron flock was 12.0 N – 18.0 N.

The character of ripping in flocked samples from all brands of paperboard and flock, glued with water-dispersive glue Eukalin and polyurethane two-component glue 1405, did not differ, only the joint strength was 32 % – 35 % lower when using glue 1405.



a



b

Fig. 4. Photo of a glued (glue Eukalin) flocked sample made from 1 mm-length Capron flock and paperboard Duoplex UD-3, after breaking off: a – view from the top; b – section view; 1 – flock coating; 2 – paperboard; 3 – glue layer

Paperboards Neoprint GD-3 and Duoplex UD-3 started delaminating immediately due to their low interlayer strength and would break off even before reaching the end of the band (Fig. 4).

Sometimes irregularities in breaking off were observed (Fig. 5). We assume that the applied force was mainly concentrated in the centre of the sample, and the ripping proceeded from the centre to the edges. The strength of paperboard surface layer on the flock-coated side was lower than that of the glued samples, therefore not just single fibres, but the whole flock coating was torn off.

The outlined area in Fig. 5 shows that at the beginning only the chalk-coated layer broke off, and then the inner layers were destroyed.

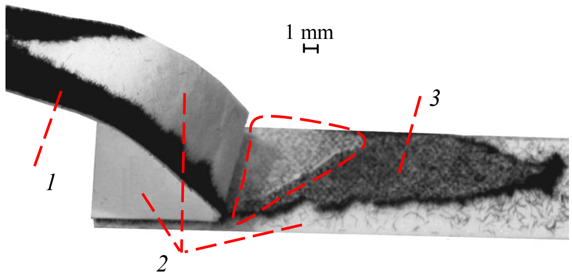
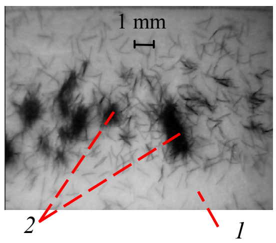


Fig. 5. Photo of a glued (glue Eukalin) flocked sample made from 1 mm-length Capron flock and paperboard Arktika GC-1, after breaking off: 1 – flock coating; 2 – paperboard; 3 – broken off flock coating

Let us try to consider the reasons of such irregularities in breaking off the fiber (Fig. 6, a – c). Firstly, it is the low strength of the applied flock when producing a flocked material; secondly, non-uniformly applied glue on the flock; thirdly, varied flock-glue contact areas, and thus resistance to breaking off.



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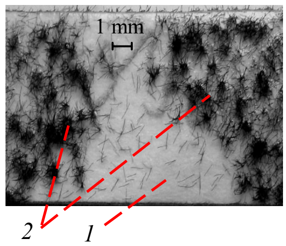

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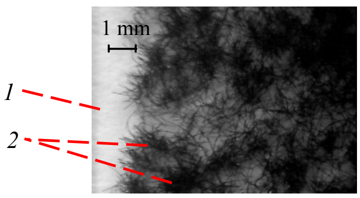

c

Fig. 6. Photo of glued (glue Eukalin) flocked samples (view from above) made from 1 mm-length Capron flock on paperboard Arktika GC-1 after breaking off: 1 – paperboard; 2 – broken off flock fibers

Taking into account the microscopic photos, the tests on the number of double folds, the measured capillary absorbancy and evaluation of the outer view of the paperboards, we have determined several characteristics of the paperboards:

1) Paperboard Alaska GC-2 is characterized by a high level of sizing (absorbancy is the lowest, MD – 0.9 cm; CD – 0.5 cm) even in the inner layers, since breaking off went along the adhesive joint (Fig. 7), no delamination was observed during the sample testing, only in certain places

(area e, Fig. 7) its inner layers got disconnected. The number of double folding – 2446 cycles MD – testifies to the high strength of paperboard Alaska GC-2 fibers (Fig. 10).

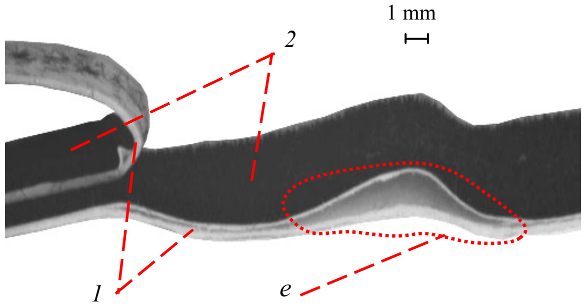

Fig. 7. Photo of a glued (glue Eukalin) flocked sample made from 1 mm-length Capron flock and paperboard Alaska GC-2, after breaking off: 1 – paperboard; 2 – flock coating; e – inner delamination

2) The value of capillary absorbancy of the paperboard Arktika GC-1 3.8 cm MD testifies to a low level of sizing, but the presence of filler enhances the absorbancy ability. At the same time, the chalk-coated reverse side worsens adhesion between the glued surfaces, thus reducing the adhesive joint strength. Paperboard Arktika GC-1 consists of three chalk-coated layers, which provide extra whiteness and smoothness, but the abrasive particles of the filler in the paperboard reduce its resistance to bending. The number of double folds in MD slightly decreases (2304 cycles, Fig. 10).

Delamination of paperboard Arktika GC-1 was observed during the breaking off of the surface chalk-coated layer, sometimes the inner layers got disconnected (fragment 1, Fig. 8) and after the breaking off the reverse side got curly (fragment 2, Fig. 8).

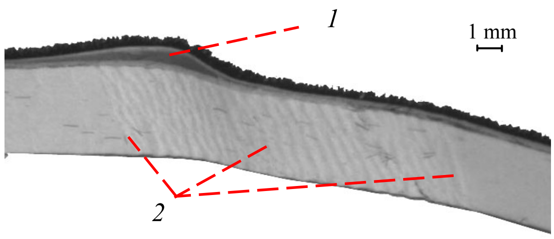

Fig. 8. Photo of a glued (glue Eukalin) flocked sample made from 1 mm-length Capron flock and paperboard Arktika GC-1, after breaking off: 1 – inner delamination; 2 – warping

It is hard to find out what caused this curl, since the paperboard consists of a mixture of different fibres that vary in their morphological structure, chemical composition and level of paper stock, as well as different fillers. Another reason for the warping might be different stresses during the breaking off and within the paperboard layers.

3) The value of capillary absorbancy of paperboard Neoprint GD-3 is 2.7 cm. This means poor sizing and presence of chalk-coated layer in it. The number of double folds (1153 cycles in MD, Fig. 10) leads to a conclusion that the strength of waste paper paperboards is twice as low, but is still sufficient, as the paperboard composition contains 10 % – 13 % cellulose.

4) Paperboard Duplex UD-3 is made from paper waste. It is also confirmed by the number of double folds that the paperboard can withstand (only 107 cycles in MD). Compared to paperboard Neoprint GD-3, the strength is ten times lower, since it is made from 100 % cheap waste paper. The photo of the sample after testing its resistance to bending (Fig. 9) shows the multiplayer structure of the paperboard and ripping of separate layers, as well as weak interlayer links.

Out of the four brands of paperboard mentioned above, Alaska GC-2 and Arktika GC-1 have strong sizing. Therefore, no paperboard delamination was observed when the samples were tested for breaking off, while in paperboards Neoprint GD-3 and Duplex UD-3 layers were destroyed because of low interlayer strength.

The most suitable materials for manufacturing flocked packaging in terms of strength and cost are cellulose paperboards based on wood pulp. Waste paper-based paperboards possess lower strength, which can be compensated by sizing.

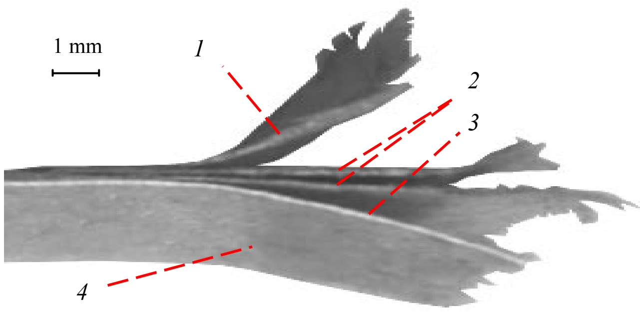

Fig. 9. Photo of flocked sample made from 0.5 mm-length Capron flock and paperboard Duplex UD-3, when testing the number of double-folds: 1 – bottom layer of the paperboard; 2 – insert; 3 – top layer; 4 – flock coating

Fig. 10 shows the dependence of the number of double folds on the paperboard brand, where a decrease in strength of paperboard with flock coating can be observed. The number of double folds of ordinary paperboard Alaska GC-2 is 2446 cycles in machine direction, while in the case of the same paperboard with 0.5 mm-length Capron flock coating it is 1155 cycles (52.8 % lower). This can be explained by the increased brittleness of the material during gluing when flock is applied on the glue layer in an electrostatic field and when the package itself is being glued.

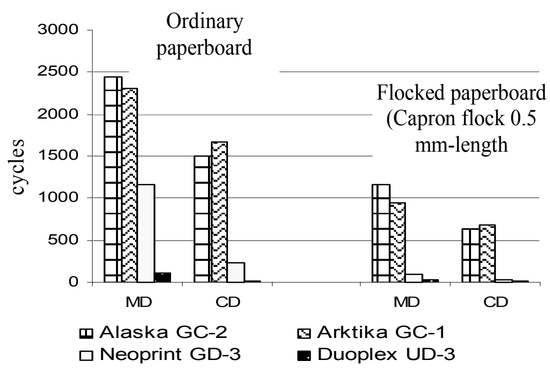

Fig. 10. Number of double folds depending on the paperboard type

Fig. 11 shows that with the increasing length of the flock, the number of double folds of the flocked material increases. Flocked samples with 0.75 mm-length flock can withstand 3 % – 4 % more tests, while flocked samples with 1.0 mm-length flock – 6 % – 7 % more than those with 0.5 mm-length flock.

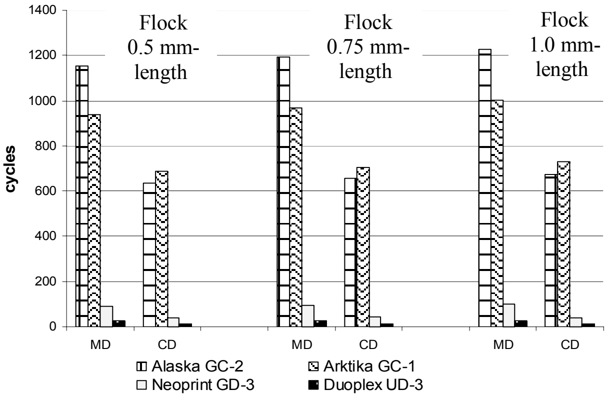

Fig. 11. Number of double folds of flock printing materials depending on the paperboard type and size of flock

As it has been mentioned before, in order to add whiteness and opacity to the paper materials, fillers are added to the composition, however, they have a negative impact on rigidity and strength. Besides, the particles of various fillers possess certain abrasive properties, which have a significant effect in determining the paper/paperboard resistance to bending.

In conclusion, it should be noted that strong adhesion of packages made from flocked materials can be obtained only when the interlayer strength of the paperboard and the strength of the gluing flock in an electrostatic field exceed the strength of the adhesive joint of the package.

A high-quality packaging material corresponds the gluing requirements and resistant to mechanical impacts, can be obtained only by considering all the aspects as a whole: the sort and length of paperboard fibres, the level of sizing, the amount of filler and other admixtures in the paper material, as well as the properties of the glue and flock.

CONCLUSIONS

1. The performed experimental testing and optical microscopy studies have demonstrated that the adhesion ripping occurred along the adhesive joint, paperboard delaminated, and flock broke off from the flocked material. Paperboards with a chalk-coated reverse side (paperboard Arktika GC-1) should not be used when gluing flocked packaging.
2. The ordinary paperboard without flock coating is characterized by high resistance to double folds (paperboard Alaska GC-2 without flock coating can withstand 52.8 % more double folds than the same paperboard with flock coating). The resistance of flocked paperboard to bending decreases almost twofold due to increased brittleness, which is caused by the adhesive composition during flock-coating.
3. The presence of mineral filler enhances absorbancy because the increased size of pores increases the interfibre absorbancy (absorbancy ability of paperboard Arktika GC-1 in machine direction is 3.8 cm by Klemm).
4. In order to preserve the filler particles in paperboard and to provide interlayer strength, the sizing is applied. The sizing should be applied both on the surface and in the mass, which would improve the paperboard resistance to delamination and its rigidity, as well as reduce absorbancy ability and provide hydrophoby.
5. The direction of fibres has a great impact on the test results both when testing flock samples in breaking off and in resistance to bending. The number of double folds of paperboard Alaska GC-2 in machine direction is 2446 cycles, while in cross-section direction – 1507 cycles (38.4 % lower).
6. Further investigation should be carried out in studying flocked materials in tension.

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