ISSN 1392 - 1207. MECHANIKA. 2007. Nr.5(67)

Investigation of mechanical strength of adhesive joints of packages made from flock printing materials

E. Kibirkstis*, O. Mizyuk**
**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: olga.mizyuk@ktu.lt*

1. Introduction

Recently, packaging industry has been developing rapidly in different areas, the variety of materials included (paper, paperboard, corrugated paperboard, films, plastics, rubber, leather), which differ in their physical-mechanical properties and can be tough, soft, flexible, porous or smooth. A considerable consumer demand can be noticed for paperboard packaging which can be characterised by the originality of its construction shapes and possibilities of postprinting finishing [1].

It is well known that high-quality packaging not only protects the goods against negative environmental effects during storage and transportation, but also provides attractive outer image for the commodities, thus increasing their competitiveness in the market. Among the latest achievements, packaging from flock printing materials is of special interest. The authors of papers [2-4] were involved in electroflocking of paper (see Fig. 1).

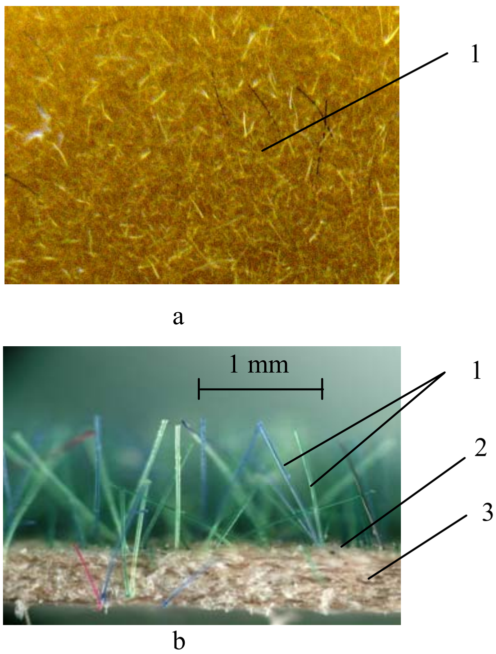

Fig. 1 Microphotography of a flock printing material: a – view from above; b – view of a section: *1* - flock, *2* - adhesive layer, *3* - paperboard

Since the technological chain of producing packaging from the above mentioned materials also includes glueing, the phenomena occuring during the process of glueing require specific investigation. This leads to further study aimed at developing high-quality flock printing packaging meeting the consumers' aesthetic demands.

During its life cycle, packaging is usually subjected to mechanical or environmental impact. Therefore, regardless of the package's outer image or the materials it is made from, the most important requirement is its mechanical strength which, depending on the forces involved, is expressed in different ways characterising the material resistance to tearing (stretching), rupture, shock load, fracture, punching, etc.

The aim of the present paper is to determine mechanical properties of a flock printing material during glueing and to define the character of ripping of adhesive joints. It has been determined [5, 6] that the decisive factor in obtaining reliable adhesion is surface preparation and adhesive properties of the glue. The effect of the angle of lubrication, surface tension, adhesion and cohesion force while glueing have been analysed in [7-15]. However, there is no generally accepted procedure of preparing and glueing materials, therefore each concrete application case has to be considered when selecting the adhesive material.

A specific feature of obtaining flock printing packaging is that glueing involves two sides: the front side, i.e., the flock printing surface, and the back side – the paperboard. A number of papers [16-18] deal with paper and paperboard studies, in which the authors analyse strength and deformation properties, testing methods, as well as strength of paper/paperboard adhesive joints.

Like in selecting glue, it is also difficult to predict the strength of paper or paperboard because of numerous influencing factors: the length and strength of the original fibres, the level and character of the fibre contexture, the level of the change in the outer surface of the fibres, the level of the sheet density, homogeneity of its formation, introduction of various additives to the paper mass and even the conditions of storing the mass for producing paper or paperboard. Moreover, the behaviour of flock printing samples at tearing and determining the stretching force is of scientific significance. Applying Peel test method in this area, scientists have investigated properties and adhesion of plastics and films [19, 20] and self-adhesive materials [21, 22].

The present paper differs from those mentioned above in the fact that it analyses the impact of materials (paperboard, glue composition, flock) used in producing flock printing packaging on its mechanical strength.

2. Research methods and equipment

For glueing the packaging, the width of band is within the limits 8-15 mm, depending on the package size. The sizes of the packages chosen for our studies (Fig. 2, a) are 165×118×48 mm and 137×77×37 mm, and the glueing width is 12 mm (Fig. 2, b), therefore the size of bands for glueing and breaking-off was 12×150 mm (Fig. 2, c). As mentioned before, the flock surface is glued to the reverse side of the paperboard and after the drying process breaking-off is performed.

Tests were carried out using the „Twing-Albert Instrument Company“ machine model 225-1 following the approach of peel adhesion 180^0 (Fig. 2, d). The speed of the specimen breaking-off 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 12 mm width and 150 mm length. The tests were performed at 24°C of ambient temperature and at 55% humidity.

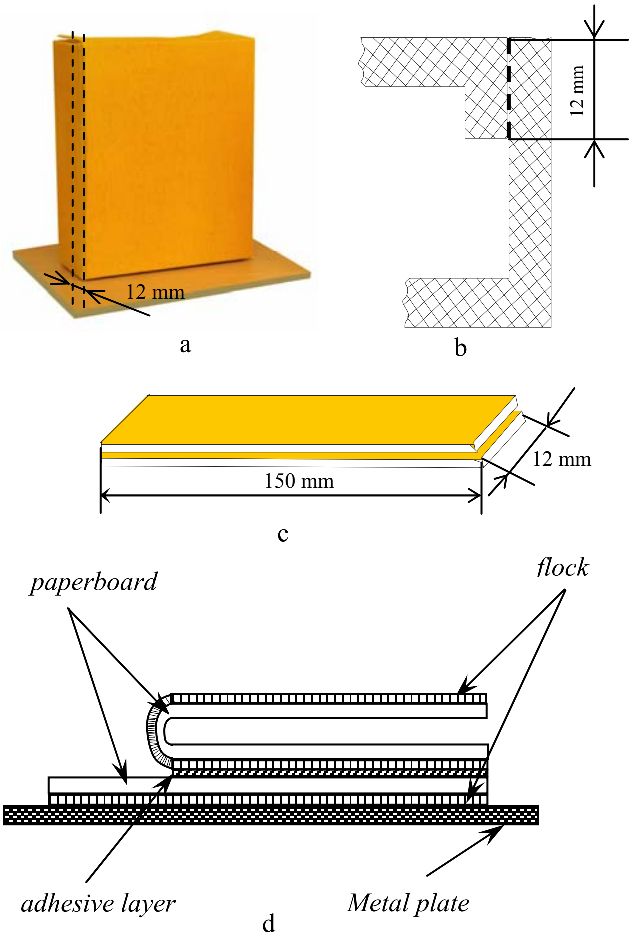

Fig. 2 Schemes of flocked samples in glueing and breaking-off: a – appearance of package; b – fragment of package adhesive joint (view from above); c – samples of studied elements of package; d – general view of method of samples breaking-off

Samples of the following paperboards were used for the investigation: Alaska GC-2 (200 g/m^2), Neoprint GD-3 (250 g/m^2), Arktika GC-1 (250 g/m^2), Duoplex (350 g/m^2) (produced by “International Paper”, Poland), as well as 0.8 mm thick plastic material, which were coated with 0.5 mm and 1.0 mm long kapron flock (linear density 3.3 dtex) and 0.75 mm long viscose flock (linear density 1.75 dtex). The glue used was polyurethane bicomponent glue 1405 and water-dispersive Eucalin. The duration of the drying process in natural environment was 1 hour for polyurethane glue and 15 sec for the water-dispersive one. The load on the specimen area of 0.012×0.15 m^2 during the glueing process was 2.47×10^4 N/m^2.

3. Analysis of research data

For comparing mechanical strength, both glued flock printing and ordinary paperboard specimens were studied. Fig. 3 shows the dependences of two paperboard types: Neoprint GD-3 (250 g/m^2) and Arktika GC-1 (250 g/m^2) in machine and cross-machine direction.

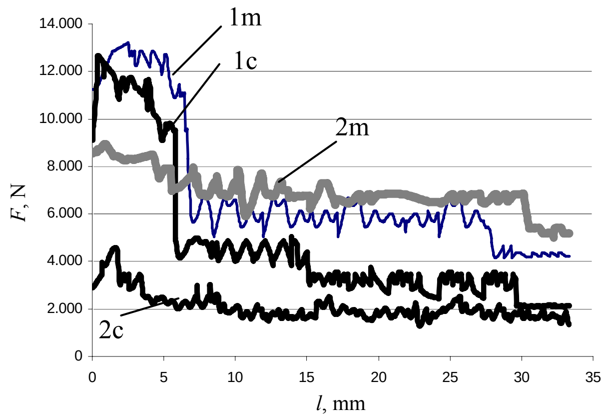

Fig. 3 Dependence of breaking-off strength of the samples on the type and direction of the paperboard: *1m* – Arktika GC-1 (MD); *1c* – Arktika GC-1 (CD); *2m* – Neoprint GD-3 (MD); *2c* – Neoprint GD-3 (CD)

Regardless of the same estate of the paperboards, the breaking-off is significantly different. In the case of paperboard Arktika GC-1, the force applied in machining direction is 12.0-13.0 N, in cross-machine direction is 9.0-12.0 N, while in the case of Neoprint GD-3 paperboard it decreases and is 6.0-8.0 N MD and 2.0-3.5 N CD. The decrease in strength shown in Fig.3 for dependences *1m* and *1c* can be explained by the fact that up to 7.0 mm the breaking-off of the sample goes along the adhesive joint, while later the paperboard starts delaminating and the force decreases. If we compare the percentage ratio of the machine and cross-machine direction, MD/CD for different paperboards is from 3/1 to 1.5/1. Therefore in glueing the packages from flock printing materials only machine-direction was considered as more resistant to delamination.

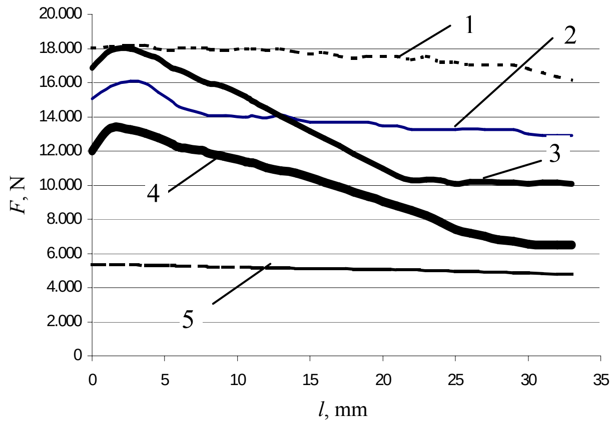

Fig. 4 Dependence of breaking-off strength of flock printing materials made from 0.5 mm long kapron flock and glued with Eukalin, on the type of the base: *1* – Alaska GC-2; *2* – Arktika GC-1; *3* – Duoplex UD-3; *4* – Neoprint GD-3; *5* – plastic

Figs. 4-6 show the dependences of breaking-off strength of flock printing samples glued together with Eukalin on the type of flock and the type of base material.

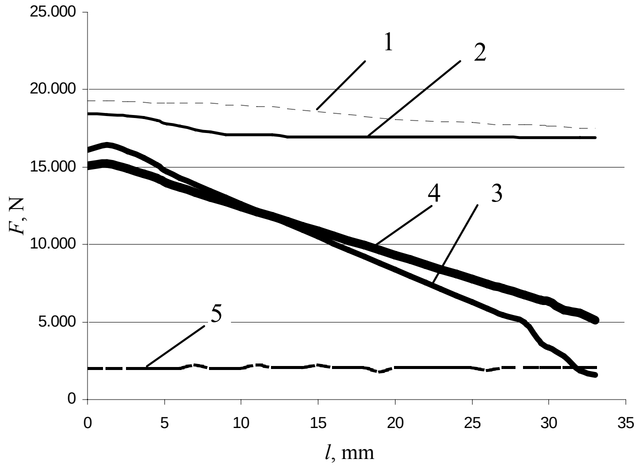

Fig. 5 Dependence of breaking-off strength of flock printing materials made from 0.75 mm long viscose flock and glued with Eukalin, on the type of the base: *1* – Alaska GC-2; *2* – Arktika GC-1; *3* – Duoplex UD-3; *4* – Neoprint GD-3; *5* – plastic

While analysing the results, it may be noted that high strength before breaking-off has been characteristic to all the three types of flock of the flock printing samples made from Alaska GC-2 and Arktika GC-1 paperboards, which had constant breaking-off force along all the length, thus leading to tearing the sample along the adhesive joint. For example, the adhesive strength of flock printing samples made from Alaska GC-2 paperboard was fluctuating within the range: 16-18 N for the 0.5 mm long kapron flock, 17.5-19 N for the 0.75 mm long viscose flock and 20-26 N for the 1.0 mm long kapron flock.

It should be noted that in the case of two other brands of paperboard - Duoplex UD-3 and Neoprint GD-3 – initially the same force is needed for breaking-off, but later the paperboard surface layer gets damaged and delaminated even up to complete tearing off of the stripe (Fig. 5, curve *3*). The force approaches zero during sample breaking-off in the range 32-34 mm.

Usually the paperboard is a multilayer material and a lot of factors may affect the strength of interlayer connections. Moreover, the increased number of paperboard layers raises the paperboard resistance to tearing at all other equal parameters, however, the resistance to delamination of the obtained fibrous material decreases.

It is known that paperboards are made from cheap and weak fibres: waste paper and semifinished products of deciduous timber. In order to meet the more rigorous requirements for packaging, the paperboard is glued both on the surface as well as in the mass, which not only increases mechanical strength, but also makes it waterproof. Adhesive materials glue together the fibres that the paperboard consists of. Therefore the bond among the fibres increases and the sheet becomes more durable. Besides, different adhesive materials may add to the paperboard smoothness, gloss, hydrophoby, greater surface resistance to abrasion, reduction of linear deformation when soaking, etc.

Analysis of dependence *5* in Figs. 4-6 shows low adhesion strength of glueing the flock and the plastic, namely, 2-5.5 N all along the tear. Both flock and plastic have surfaces that are hard to glue due to low adhesion, therefore this fact should be kept in mind when producing flock printing packaging from similar materials.

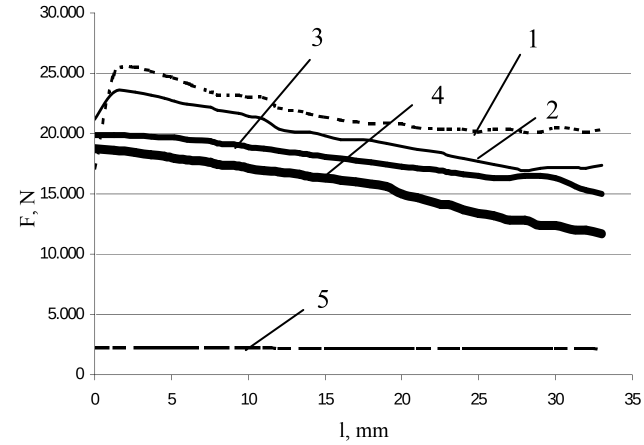

Fig. 6 Dependence of breaking-off strength of flock printing materials made from 1.0 mm long kapron flock and glued with Eukalin, on the type of the base: *1* – Alaska GC-2; *2* – Arktika GC-1; *3* – Duoplex UD-3; *4* – Neoprint GD-3; *5* – plastic

The dependences presented in Figs. 7-9 show that when applying polyurethane composition 1405, the breaking-off strength of the flock printing samples from all the paperboard brands decreases, but surprisingly, the adhesive strength of the plastic material increases.

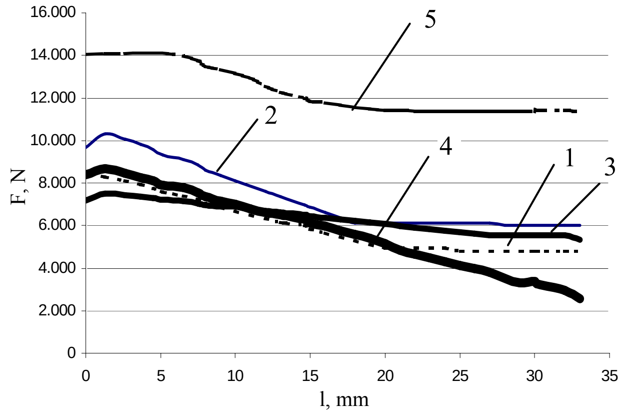

Fig. 7 Dependence of breaking-off strength of flock printing materials made from 0.5 mm long kapron flock and glued with adhesive 1405, on the type of the base: *1* – Alaska GC-2; *2* – Arktika GC-1; *3* – Duoplex UD-3; *4* – Neoprint GD-3; *5* – plastic

The mechanism of connecting flock and plastics can be explained by the specific adhesion theory: the presence of forces of attraction between the adhesive and the substrate, where surface-active substances are introduced into the molecules of the adhesive since two smooth surfaces are being glued. Durable bonding is formed by specific molecular forces: surface tension, adsorption or chemical bonds. From the point of view of diffusion theory, polymer adhesion is influenced by the properties of their molecules, molecular mass, formation of macromolecules which in their turn determine the properties of the adhesive to dissolve in the substrate and diffuse in it. When the molecular mass of the adhesive increases, the number of free molecules able to diffuse in the substrate decreases. These factors should be considered when glueing problematic materials.

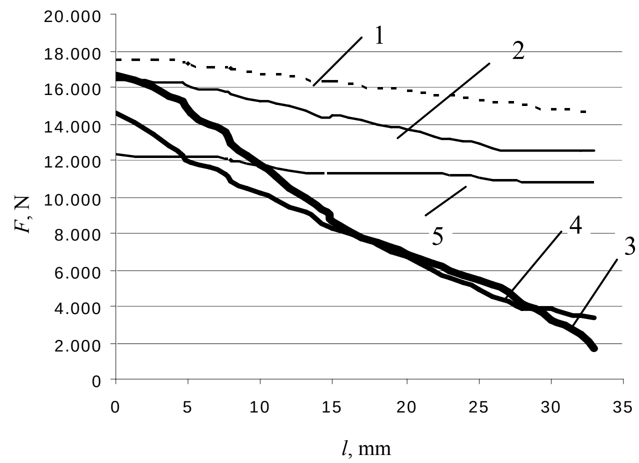

Fig. 8 Dependence of breaking-off strength of flock printing materials made from 0.75 mm long viscose flock and glued adhesive 1405, on the type of the base: *1* – Alaska GC-2; *2* – Arktika GC-1; *3* – Duoplex UD-3; *4* – Neoprint GD-3; *5* – plastic

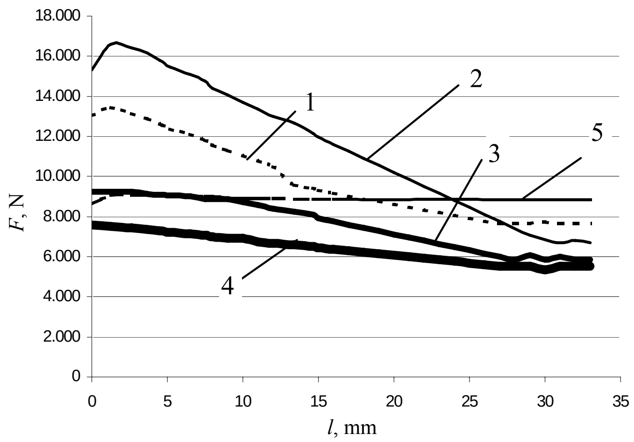

Fig. 9 Dependence of breaking-off strength of flock printing materials made from 1.0 mm long kapron flock and glued with adhesive 1405, on the type of the base: *1* – Alaska GC-2; *2* – Arktika GC-1; *3* – Duoplex UD-3; *4* – Neoprint GD-3; *5* – plastic

Let us consider the effect of the type of the flock and its measurements on breaking-off strength of the samples under test. In the case of paperboard Alaska GC-2 (Fig. 10) and water-dispersive glue Eukalin, the breaking-off strength for all types of flock is within the range 16-25 N, while with the polyurethane adhesive 1405 the range is 5-15 N, which testifies to the significance of selecting an appropriate adhesive composition. Kapron flock belongs to synthetic fibres, while viscose is an artificial fibre. Viscose fibre, in comparison to kapron, is less durable. However, the flock printing sample from 0.75 mm-long viscose fibre (Fig. 10, curve *2b*) is an exception, it possesses higher strength when glued with the polyurethane adhesive. As mentioned above, both the adhesive substances and the flock materials differ in their nature and structure. They contain polar and non polar groups, complex formation, intermolecular forces or combined effect of various bonds. Therefore, in this case the mechanism of adhesion can be explained by several theories of adhesion. Besides, both the adhesive substances and the surfaces to be glued have to be selected with similar properties of their chemical composition.

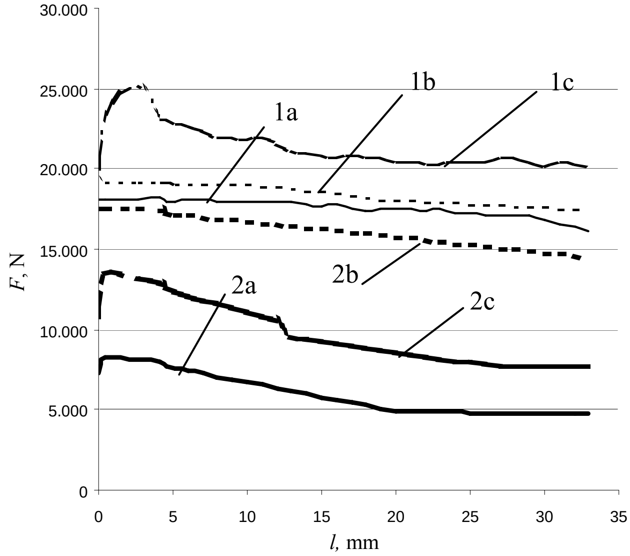

Fig. 10 Dependence of breaking-off strength of flock printing samples made from Alaska GC-2 paperboard on the type of flock and glue: *1* – water-dispersive Eukalin; *2* – polyurethane 1405; *a* – 0.5 mm long kapron flock; *b* – 0.75 mm long viscose flock; *c* – 1.0 mm long kapron flock

Let us consider the dependences in Figs. 4-6 in terms of the flock measurements, i.e., its length and thickness. With all the paperboard brands (Alaska GC-2, Arktika GC-1, Duoplex UD-3 и Neoprint GD-3), the breaking-off strength of the 0.5 mm long kapron flock ranges between 12 and 18 N, the 0.75 mm long viscose flock – 15-19 N, the 1.0mm kapron flock – from 16 to 26 N. The increase in flock length increases pre-tearing strength of the glued samples. In addition to adhesive properties of the glue, the flock-glue contact area is of great importance. Consequently, the strength of the flock printing sample joints will change when changing the flock-glue contact area which depends on the flock length, its thickness and the depth of penetration into the glue layer. But all these parameters have to be strictly coordinated among each other. Besides, the test results have shown that the 1.0 mm long kapron flock got deeply fixed in the glue layer and paperboard delamination was rare since tearing occurred along the adhesive joint; sometimes even strength of the joint was higher than the strength of the flock on the paperboard. Parts of the flock would be torn off the flock printing paperboard together with the adhesive.

When comparing the 0.5 mm long kapron flock (Fig. 4) with the 0.75 mm long viscose flock (Fig. 5), we may notice almost the same pre-tearing strength. In addition to the increased length of the viscose flock, they are of different thickness. Linear density of the kapron flock is 3.3 dtex, while that of the viscose flock is 1.75 dtex. Length-thickness ratio of the flock is linear, i.e., increased thickness of the flock at preserving the same length, and reduced length at preserving the same thickness result in stronger adhesion.

In conclusion, it should be noted that the performed experimental tests allowed us to see the behaviour of the "paperboard-glue-flock" materials when glueing the flock printing packaging. Selection of the adhesive material turned out to be of great importance. It was also essential to study certain characteristics like surface structure, the number of layers, the impact of sizing of the paperboard on the glueing process of flock printing samples. Therefore, further studies should be developed in the area of physical-mechanical and chemical-mechanical properties of the materials. Investigation of the structure of flock printing materials during glueing by using electronic-microscopic methods is of special interest.

4. Conclusions

1. The paperboard grammage has no effect on the strength of the adhesive joints when glueing flock printing packaging. The adhesive strength of paperboard Neoprint GD-3 (250 g/m^2) sample in machine direction is 6.0-8.0 N, while that of paperboard Arktika GC-1 (250 g/m^2) is double high: 12.0-13.0 N at the same mass.

2. For testing the glued flock printing samples, machine direction was considered as more resistant to delamination, since the MD/CD strength ratio was determined as 3/1 to 1.5/1 for different paperboard brands.

3. The character of the adhesive joint rupture was defined: in the case of Alaska GC-2 and Arktika GC-1 paperboards, the breaking-off was along the adhesive joints, while Duoplex UD-3 and Neoprint GD-3 experienced paperboard delamination due to low surface and interlayer strength of the paperboard.

4. When selecting the adhesive composition chemical properties, composition and surface tension of the adhesive and the substrate should be considered.

5. It has been determined experimentally that during breaking-off of different type and size flock samples, the 1.0 mm long fibres ensure the highest pre-tearing strength (up to 26 N). This can be explained by the flock-glue contact area which depends on the flock length, its thickness and penetration into the glue layer. Consequently, the ratio of flock length and thickness should be considered as it can increase or decrease the adhesion area and tearing force.

6. The type of fibre has an effect on the adhesion strength. Kapron flock is stronger than viscose, however, the type of the glue should also be considered.

7. It has been determined that both surface and mass sizing increases the resistance to delaminating and tearing. However, the level of sizing and its effect on the adhesive properties of the paperboard still need to be studied.

8. The obtained test results can be further applied in planning adhesion of flock printing packages.

References

1. **Regej, I.I.** Cardboard packaging.-Packing, 2006, No5, p.26-28. (in Ukrainian).
2. **Havenko, S.F., Mizyuk, O.M., Rybka, R.V., Shaplinsky, O.D.** Technology of packages design by electroflocking. -Packing, 2005, No.3, p.58-59. (in Ukrainian).
3. **Mizyuk, O.M., Rybka, R.V., Havenko, S.F.** Electrical flocking as a coating technique of elite packages. Proceedings of the 3rd scientific and practical conference „The Modern Technologies in Packaging", Kiev, 2007, p.69-74. (in Ukrainian).
4. **Havenko, S., Mizyuk, O., Rybka, R., Kibirkstis, E., Zubrickaite, L.** Study of physical aspects of electrofłocking (flock printing).-J. Materials Science (Medžiagotyra), 2007, v.13, No.3, p.206-209.
5. **Duncan, B., Abbott, S., Court, R., Roberts, R. and Leatherdale, D.** A Review of Adhesive Bonding Assembly Processes and Measurement Methods. NPL Report MATC(A)135, 2003.-73p.
6. **McKnight, M.E., Seiler, J.F., Nguyen, T., and Rossiter, W.J.** Measuring peel adhesion of coatings. -J. of Protective Coatings & Linings, 1995, v. 12, No.5, p.82-89.
7. **Yang, Q.D., Thouless, M.D.** Mixed-mode fracture analyses of plastically deforming adhesive joints. -Int. J. of Fracture, 2000, No.110(2), p.175-187.
8. **Cherian, Z., Lehman, R.** Effects of adhesive type and polystyrene concentration on the shear strength of bonded polystyrene/high-density polyethylene blends. -Int. J. of Adhesion & Adhesives, 2005, No.25, p.502-506.
9. **Yu, J., Song, J.Y., and Park, I.S.** Analyses of the practical adhesion strengths of the metal/polymer interfaces in electronic packaging.-J. of Electronic Materials, 2002, v.31, No.12, p.1347-1352.
10. **Romero-Sánchez, M.D., Walzak, M.J., Torregrosa-Maciá, R. and Martín-Martínez, J.M.** Surface modifications and adhesion of sbs rubber containing calcium carbonate filler by treatment with uv radiation. –Int. J. of Adhesion and Adhesives, 2006, v.27, issue 6, p.434-445.
11. **Vega-Baudrit, J., Sibaja-Ballestero, M., Vázquez, P., Torregrosa-Maciá, R. and Martín-Martínez, J.M.** Properties of thermoplastic polyurethane adhesives containing nanosilicas with different specific surface area and silanol content.-Int. J. of Adhesion and Adhesives, 2006, v.27, issue 6, p. 469-479.
12. Atomic Force Microscopy in Adhesion Studies / edited by J.Drelich, Kach L. Mittal.-Leiden: VSP, 2005.-812p.
13. Adhesion: Current Research and Applications / edited by Wulff Possart.-Wiley-VCH, 2005.-576p.
14. Contact Angle, Wettability and Adhesion. Editor: K.L. Mittal.-Utrecht Boston: VSP, 2003, v.3.-520p.
15. **Olah, A., Vancso, G.J.** Characterization of adhesion at solid surfaces: development of an adhesion-testing device.-European Polymer Journal, 2005, v.41, issue 12, p.2803-2823.
16. **Stenberg, N.** Mechanical Properties in the Thickness Direction of Paper and Paperboard // Preparation and Testing of Adhesive Joints.-Measurement Good Practice Guide, 2001, No.47.-77p.
17. **Flate, D.** Properties of Paper.-Moscow: Wood industry, 1986.-680p. (in Russian).
18. **Kibirkstis, E., Kabelkaite, A.** Research of paper/paperboard mechanical characteristics. – Mechanika.-Kaunas: Technologija, 2006, No.3(59), p.34-41.
19. **Song, R., Chiang, M.Y.M., Crosby, A.J., Karim, A., Amis, E.J. and Eidelman, N.** Combinatorial peel tests

for the characterization of adhesion behavior of polymeric films.-Polymer, 2005, v.46, issue 5, p.1643-1652.
20. **Wei, Y. and Hutchinson, J.W.** Interface strength, work of adhesion and plasticity in the peel test. -Int. J. of Fracture, 1998, No.93, p.315-333.
21. **Chiche, A., Zhang, W., Stafford, C.M. and Karim, A.** A new design for high-throughput peel tests: statistical analysis and example.-Meas. Sci. Technol., 2005, No.16, p.183-190.
22. **Zhao, B., Pelton, R.** Peel adhesion to paper — interpreting peel curves.-J. Adhesion Sci. Technol., 2003, v.17, No.6, p.815-830.

E. Kibirkštis, O. Mizyuk

PAKUOČIŲ, KURIŲ MEDŽIAGA SU ĮKLIJUOTU PŪKU, KLIJUOTINIŲ SUJUNGIMŲ MECHANINIO STIPRUMO TYRIMAS

R e z i u m ė

Straipsnyje pateikiami naujausi pakuočių klijuotinių sujungimų atsparumo tyrimai. Pakuotės yra pagamintos iš kartono su įklijuotu pūku. Eksperimentinių tyrimų metu nustatytas bandomųjų pavyzdžių irimo pobūdis ir atplėšimo jėga, taip pat medžiagų (kartono, klijų, pūko) savybių įtaka suklijavimo stiprumui.

Nustatyta atplėšimo jėgos priklausomybė nuo medžiagos savybių ir jos tipo. Aptiktos dvi klijuotinio sujungimo irimo kryptys: 1) irimas pagal suklijavimo jungiamuosius paviršius; 2) kartono irimas sluoksniais. Kad klijuotinis sujungimas būtų stiprus, nustatytos sąlygos ir būdai kartono irimui sluoksniais pašalinti. Eksperimentiškai patvirtinta, kad klijuotinio sujungimo stiprumui (iki suirimo), kartono gramatūra įtakos neturi. Šiuo atveju įtakos turi plaušelių orientacijos kryptis (mašininė ar skersinė liejimo kryptis). Nustatyta, kad, didėjant elementarių kartono sluoksnių skaičiui, pasipriešinimas kartono irimui sluoksniais mažėja.

E. Kibirkštis, O. Mizyuk

INVESTIGATION OF MECHANICAL STRENGTH OF ADHESIVE JOINTS OF PACKAGES MADE FROM FLOCK PRINTING MATERIALS

S u m m a r y

The paper presents the latest investigation of the strength of adhesive joints of packages made from flock printing material. During the experimental testing, the character of ripping and tearing strength of the samples as well as the influence of the properties of materials (paperboard, adhesive, flock) on the strength of adhesion have been determined.

The dependence of tearing strength on the properties of the material and its type has also been found. Two ripping directions of adhesive joints have been determined: 1) ripping along joining surfaces of the adhesion; 2) ripping of paperboard in layers. The conditions to obtain firm adhesion and the ways to eliminate ripping of the paperboard in layers have been determined. It was found experimentally that grammage of the paperboard makes no influence on the strength of adhesive joints (tearing off). For this case, it is the orientation direction of the fibres (machine or cross-machine direction) that makes the influence. It has been determined that the resistance to ripping of the paperboard in layers decreases with the increase of the number of elementary layers of the paperboard.

Э. Кибиркштис, О. Мизюк

ИССЛЕДОВАНИЕ МЕХАНИЧЕСКОЙ ПРОЧНОСТИ КЛЕЕВЫХ СОЕДИНЕНИЙ УПАКОВОК ИЗ ФЛОКИРОВАННЫХ МАТЕРИАЛОВ

Р е з ю м е

В статье исследована прочность клеевых соединений упаковок из флокированных материалов, которые относятся к новейшим разработкам. В ходе проделанных экспериментов установлен характер разрушения и разрушающая сила исследуемых образцов, а также влияние свойств материалов (картона, клея, флока) на прочность склеивания.

В результате исследований получены зависимости разрушающего усилия от вида и размерных показателей материалов. Выявлены два направления, в которых происходит разрушение клеевого соединения: 1) по клеевому шву; 2) при отрыве происходит расслоение картона. Установлены причины и способы устранения расслоения картона для обеспечения прочной склейки. Экспериментально подтверждено, что на прочность до отрыва грамматура картона не влияет, тогда как влияние оказывает направление волокон картона (машинное или поперечное). Исследовано, что при увеличении количества элементарных слоев картона величина сопротивления расслаиванию полученного материала уменьшается.

Received July 19, 2007