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Influence of Technological Factors on Physical and Mechanical Properties of Laminated Prints

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Research of qualitative parameters of lamination at different technological modes for different papers is carried out. Influence of temperature and speed of print lamination with an OPP film on the quality of laminates is considered. A mathematical model describing the strength and curling of a laminate depending on the regime factors of the process has been developed. Optimization of the technological process has been carried out.

Keywords: technological processes, lamination optimization, polypropylene films

0 INTRODUCTION

Finishing prints by means of pressing a transparent film gives a significant effect in mass production at low costs: it improves aesthetic and advertising qualities; gives ample opportunities of creative designing; provides the best protection of a surface against mechanical damages and the environmental impact [1].

In the world practice of polygraphic industry three basic ways of laying a polymeric material over paper are used:

1) Glueing the film on the paper by using varnish or glue (a glutinous way);
2) Pressing the duplicated film, one layer of which has considerably lower temperature of fusion than the other, and carries out thermoglue functions during pressing (a glueless way);
3) Coating paper with fusion polymer which acts as thermoglue during the coating process, and after cooling and hardening serves as protective coating (extrusion, co-extrusion).

When choosing a film for lamination, it is necessary to consider the purpose of the laminate, as well as its appearance. The most promising material for lamination is oriented polypropylene (OPP) as it is a strong, elastic, ageproof and rather inexpensive material. Other OPP advantages are high transparency, shine, low specific weight; therefore it represents special interest for lamination of polygraphic production [2].

Study on rough-surface biaxially oriented polypropylene film is presented in [3]. The influence of processing conditions on the roughness state of BOP was generally similar to that in the case of monolayer cast sheet.

Three different techniques for experimentally determining the bending stiffness of flexible films and laminates have been evaluated using a number of different packaging materials [4]. The calculations showed that layer modulus often is less important than layer thickness and that the position of the layer in the laminate can have a major influence on the overall stiffness.

Permanence and strength of digital prints on paper are show in [5]. Colour prints with a surface protection of polymer varnish or foil protection are very unstable, causing deterioration of colour, contrasts and colour balance.

With the big assortment of lamination films and a great variety of laminated materials, there is an urgent problem of defining optimum technological modes of lamination that would allow to reduce the duration of performance and to raise the quality of production [6].

The aim of this paper was to research qualitative parameters of lamination at different technological modes, as well as to develop the mathematical model of the lamination process for optimizing the mode parameters of the lamination process.

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1 METHODOLOGY OF RESEARCH

The mechanical properties of the films were investigated by a tensile machine: samples of a film 15×250 mm, distance between the clips of the tensile machine - 180 mm, speed of movement of the bottom clip - 100 mm/min. Measurements were taken in the longitudinal and cross-sectional directions of the film orientation. Strength at break σ_R (kPa) and lengthening at break ε_R (%) were also measured.

Contraction (%) (relative change of length of a film after its thermal processing and cooling to normal temperature):

$$S = \frac{L_0 - L_1}{L_0} 100\% \qquad (1),$$

where L_0 is the initial length, L_1 is the length after thermal processing and cooling.

Tests were carried out for two directions (longitudinal and cross-sectional), on samples of the size 100×100 mm at temperature 90 to 130 °C (depending on the kind of film) during 15 minutes. The accuracy of measurement was – 0.1 %.

Adhesive strength of laminating a duplicated OPP film to prints was defined by the method of stratification on the dynamometer. For this purpose samples of laminates were taken: strips in width of 15 mm and length 150 mm, which were not laminated on one side (so that there were ends in length of 20 mm for fixing in the dynamometer clamps). The maximum loading which caused tear of the film from the paper was fixed as the result of the tests. The parameters of strength of fastening a film to paper were taken as an arithmetic mean of three tests. Strength of lamination should make not less than 20 kPa [7].

An objective criterion of good adhesive interaction of glue with paper and a polymeric film is the factor of strengthening of the system:

$$K_{sh} = f_l \,/\, (f_p + f_f) \qquad (2),$$

where f_l, f_p, f_f are the breaking strength of the laminate and the initial materials: paper and polymeric film accordingly, kPa.

At the correct choice of lamination modes this factor $K_{sh} > 1$.

The quality of lamination was also investigated by means of Friction/Peel Tester 225-1. The value of the force necessary for detaching laminate from the basis and the character of its change were established.

For testing, 15 mm wide and 300 mm long samples from each laminated sheet of paper in the longitudinal and cross-sectional direction of lamination were prepared. The laminate was separated from the basis at an angle of 180 degrees with the speed of 50 mm/min.

Curl (deformation) of the sample is characterized by the size of rise of corners in relation to the horizontal surface, and also the ratio of the size of approximation of the sample edges to its middle all along the length of the sample, expressed in percentage. The lamination quality is considered good if the size of deformation of the sample does not exceed 5 % [8].

For determining the curling of laminates, samples were cut out from each sheet in the size of 100×100 mm and the height of rise of two opposite corners in relation to the plane of the table were measured. The exponent of twisting is the height of the edge rise of the sample in relation to the surface of the table in mm^{-1} [9].

The search of optimum parameter values for mathematical models of lamination process (dependence of strength of lamination and curling of laminates on temperature, speeds and weights of paper) was performed by applying the method of least squares [10] and [11].

Calculation of parameters of the obtained models and all following calculations were carried out by means of computer mathematical system Maple V [12].

2 RESEARCH OF TECHNOLOGICAL PARAMETERS OF LAMINATION PROCESS WITH OPP FILMS

Under certain technological conditions during lamination the polymeric film forms a new combined system with a print 'film-paper-film' whose properties are defined by the properties of a substratum, adhesive and modes of lamination. Factors which influence the quality of lamination can be divided into mode and technological ones. The process modes depend on technological factors and are selected according to the properties of the substratum, in view of the capabilities of the equipment.

The quality of laminated production is defined by three parameters: fastening strength of the package 'film-paper-film', curling of laminates which testifies to the presence of internal pressure in the system, absence of outer defects (strips, morel, bubbles, etc.).

It is experimentally confirmed that adhesive strength of the system 'film-paper-film' depends on the character of initial materials and the mode of lamination. Besides, the temperatures and the total pressure, which intensify the penetration of the adhesive into the substratum pores, have the decisive effect on the results of lamination.

For revealing quality indicators and the optimum lamination mode, the basic physical-mechanical properties of prints and OPP films for lamination were determined.

The analysis of dependences of films 'lengthening-loading-lengthening' (Fig. 1) gives a more detailed understanding about their rheological (elastic-plastic) properties. An OPP film, 27 microns in the longitudinal direction, is easily extended at insignificant loading (dependence curve 1 sharply goes upwards). And on the contrary, in a cross-sectional direction at constant increase in loading the insignificant gradual increase in lengthening is observed (see curve 2). Such character of curves specifies the cross-sectional orientation of the film. Curve lengthenings 3 and 4 for a film of 80 microns are characteristic for nondirectional films, the strength of such a film is provided with significant thickness, instead of orderliness of molecular structures.

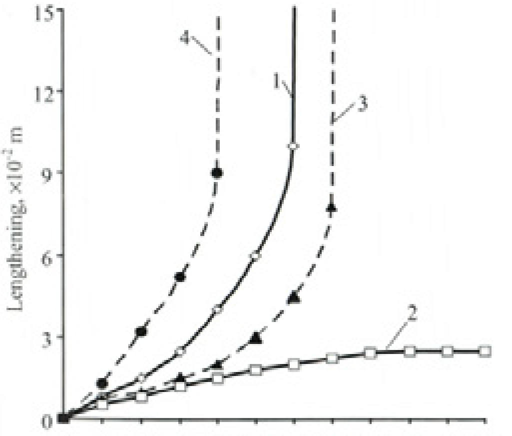


Fig. 1. *Dependence of relative lengthening upon loading for OPP films thickness 27 microns: 1 - longitudinal direction; 2 - cross-sectional direction; 80 microns: 3 - longitudinal direction; 4 - cross-sectional direction*

Anisotropism and high structure of an OPP film 27 microns thick in the cross-sectional direction also proves to be true by the diagram contraction (Fig. 2). In the longitudinal nondirectional direction the film has considerably smaller contraction than in the cross-sectional focused one. Films with 60 and 80 micron thickness are nondirectional and also have isotropic properties - their contraction makes up 0.4 % and 0.3 %, respectively, in both directions.

Investigation of quality indicators of lamination (strength of lamination and curling laminates) at different technological modes (the temperature of lamination and speed) for different papers is shown in graphic dependences Figures 3 and 5.

Figure 3 shows that the increase in the temperature of lamination leads to the increase in strength of fastening a film with paper, and the process is influenced essentially by the weight of a substratum. Thus, in order to obtain laminates with strength of adhesive fastening 20 kPa for the paper mass 80 g/m², the temperature of lamination should make 96 degrees; for the paper mass 120 g/m² - 110 degrees; for the paper mass 150 g/m² - 135 degrees.

With the increase of lamination speed (reduction of contact time of a package 'paper-film' with the heated surface of the shaft), the strength of lamination decreases (Fig. 3, b). So, at the lamination temperature of 110 degrees in order to obtain sufficient strength of an adhesive fastening (20 kPa), for the paper mass 80 g/m² lamination speed of 5 m/min is necessary; for paper 120 g/m² - 4 m/min., 150 g/m² - 3,2 m/min.

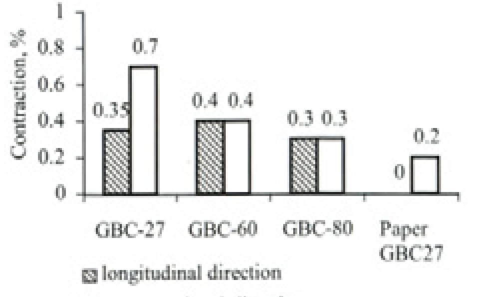
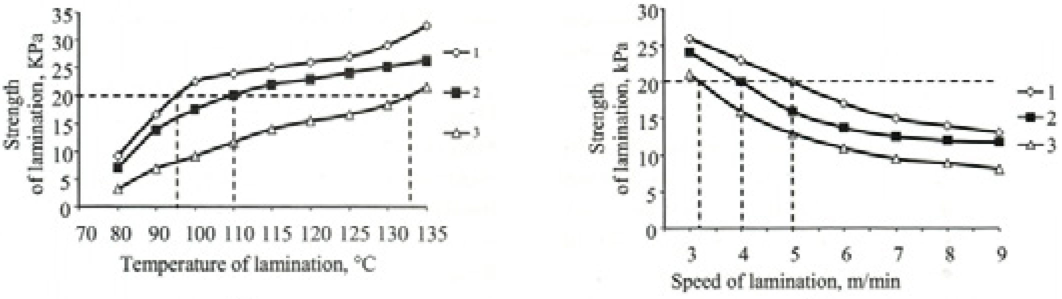


Fig. 2. *The diagram contraction of OPP films at temperature 100 degrees*



a) b)

Fig. 3. *Dependence of strength of lamination on temperature (a) and speed of lamination (b) for a paper in weight: 1 – 80 g/m²; 2 – 120 g/m²; 3 – 150 g/m²*

The analysis of the dispersion of the values of the laminate detachment force (see Fig. 4) indicates that it is small and does not exceed 4 % in the longitudinal direction (the greatest dispersion of sample 1 - up to 3.9 %). In the cross-sectional direction it is much higher (sample 2 up to 6.3 %). Dispersion of the values of the detachment force in sample 3 both in the longitudinal direction and in the cross-sectional direction is small (about 1 %) which testifies to high quality lamination.

Dependences in Figure 5, a show that with the increase in lamination temperature propensity of laminates to deformation rises and they start to curling. And the smaller the mass of the paper, the more it is deformed. So, at the lamination temperature of 100 degrees curling is observed in paper mass 80 g/m² on 7 mm, paper mass 120 g/m² - on 3 mm, and papers mass 150 g/m² - on 1.5 mm. With increasing speed of lamination (reduction of time of contact) deformation of laminates decreases (Fig. 5, b). So, if the process of lamination occurs at the speed of 6 m/min., the paper mass 80 g/m² is deformed on 8 mm, paper mass 120 g/m² - on 6 mm, mass 150 g/m² - on 4 mm.

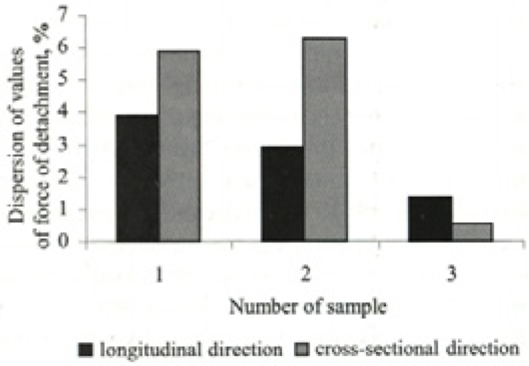
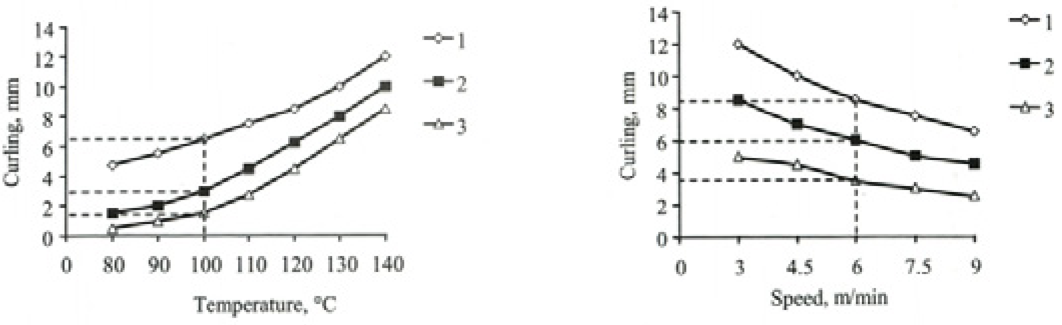


Fig. 4. *Dispersion of values of force of detachment of a laminate for the laminated prints: 1 – weight of papers 220 g/m², digital type of printing, thickness of a film 42 µm, temperature of lamination 200 °C, 2 – weight of papers 150 g/m², offset type of printing, thickness of a film 26.5 µm, temperature of lamination 115 °C, 3 – weight of papers 300 g/m², offset type of printing, thickness of a film 26.5 µm, temperature of lamination 230 °C*



a) b)

Fig. 5. *Dependence of curl laminates on lamination temperature (a) and speeds of lamination (b) for papers in weight: 1 – 80 g/m², 2 – 120 g/m², 3 – 150 g/m²*

Thus, as regime and technology factors have an ambiguous influence on quality indicators of lamination (strength of lamination and curling of a laminate), for finding optimum parameters of the lamination process in each special case, it is necessary to carry out its mathematical modelling and optimization.

To obtain the mathematical model of strength of lamination, a great number of possible functional dependences have been checked, including the following:

$$Q_1(T,V,m)=a+b\cdot m+c\cdot T+d\cdot V \qquad (3),$$

$$Q_2(T,V,m)=a+b\cdot\sqrt{m}+c\cdot T+d\cdot V \qquad (4),$$

$$Q_3(T,V,m)=a+b\cdot m+c\cdot\sqrt{T}+d\cdot V \qquad (5),$$

$$Q_4(T,V,m)=a+b\cdot m+c\cdot T+d\cdot\sqrt{V} \qquad (6),$$

$$Q_5(T,V,m)=a+b\cdot\ln(m)+c\cdot T+d\cdot\sqrt{V} \qquad (7),$$

$$Q_6(T,V,m)=a+b\cdot\ln(m)+c\cdot T+d\cdot\ln(V) \qquad (8),$$

$$Q_7(T,V,m)=a+b\cdot m+c\cdot T+d\cdot\ln(V) \qquad (9),$$

$$Q_8(T,V,m)=a+b\cdot m+c\cdot\ln(T)+d\cdot\ln(V) \qquad (10).$$

The most suitable model for the description of the dependence of lamination strength on the paper weight, temperature and speed was the following expression:

$$\begin{aligned}\mathrm{Q}(\mathrm{T},\mathrm{V},\mathrm{m})&=9.030779-0.1725819\cdot\mathrm{m}+\\&+0.3603514\cdot\mathrm{T}-8.4169\cdot\ln(\mathrm{V})\end{aligned} \qquad (11).$$

The results of lamination strength obtained by this model provide the least values of root-mean-square deviations among all the considered, which makes 1.445.

The analysis of experimental data characterising the curl of laminates has been carried out under a similar scheme.

The following functional dependence describes most precisely the dependence of laminate curling on the weight of the paper and regime factors:

$$\begin{aligned}\mathrm{C}(\mathrm{T},V,m)&=-0.6026537-0.08597808\cdot\mathrm{m}+\\&+0.1602864\cdot\mathrm{T}-0.5311999\cdot\mathrm{V}\end{aligned} \qquad (12).$$

The root-mean-square deviation of the values of deformation of laminates obtained by this model was the least from all considered and was equalled 0.979.

According to technological requirements, the strength of lamination is considered sufficient when it exceeds 20 kPa:

$$\mathrm{Q}(\mathrm{T},\mathrm{V},\mathrm{m})>20 \qquad (13).$$

The inequality leads to a conclusion that for paper mass $\overline{m}$ at working speed $\overline{V}$, the temperature of lamination should satisfy the following inequality:

$$\begin{aligned}T>27{,}66527+0{,}4789266\cdot\overline{\mathrm{m}}+\\+23{,}35748\cdot\ln\left(\overline{\mathrm{V}}\right)\end{aligned} \qquad (14).$$

As the admissible curling of paper at lamination should not exceed 5 mm:

$$\mathrm{C}(\mathrm{T},\mathrm{V},\mathrm{m})\,\mathrm{d}\leq 5 \qquad (15).$$

Hence, for paper mass at working speed the temperature of lamination should satisfy the inequality:

$$T\leq 41{,}1928596+0{,}536403\cdot\overline{\mathrm{m}}+3{,}314068\cdot\overline{\mathrm{V}} \qquad (16).$$

So, according to conditions (14) and (16) for maintenance of qualitative lamination, the working temperature should satisfy the inequality:

$$T_{\min}\left(\overline{m},\overline{V}\right)<T<T_{\max}\left(\overline{m},\overline{V}\right) \qquad (17),$$

where,

$T_{\min}(m,V)=27.66527+0.478927\cdot m+23.35748\cdot\ln(V)$,

$T_{\max}(m,V)=41.19286+0.536403\cdot m+3.314068\cdot V$.

According to this condition, to ensure qualitative lamination, the area of admissible values of temperatures depending on the weight of paper and working speed is limited to surfaces $T_{\min}(m,V)$ and $T_{\max}(m,V)$ with (Fig. 6). The figure shows that not at all speeds it is possible to reach qualitative lamination for paper of a certain weight. The possible admissible values of speeds are limited to a curve of section of surfaces and defined by the inequality:

$$T_{\min}(m,V)<T_{\max}(m,V) \qquad (18).$$

So, using the mathematical models which describe strength of lamination (11) and twisting of a laminate (12), it is possible to define areas of admissible working speeds and temperatures which provide corresponding quality of laminate covers at the maximum productivity of technological process and the minimum power inputs.

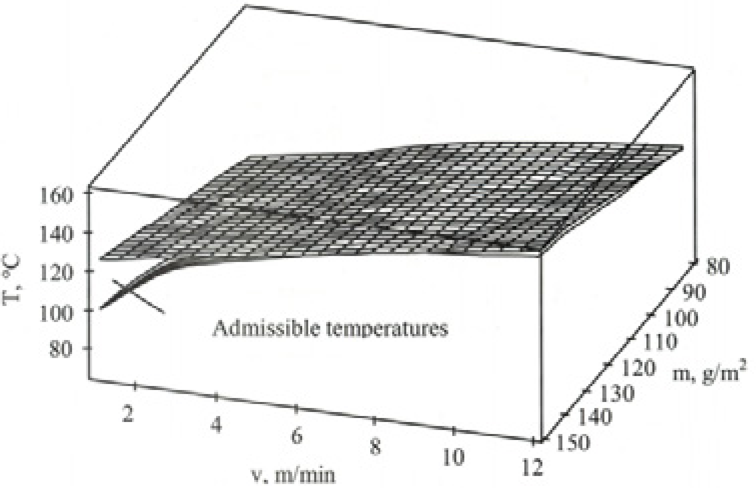


Fig. 6. *Dependence of admissible temperatures of lamination on speed of lamination and weight of paper*

Thus, as a result of the analysis of experimental data, models describing strength of lamination and twisting of laminates with sufficient accuracy, depending on the weight of paper and regime parameters, have been obtained. The obtained models have allowed us to establish conditions at which optimum temperature and speed of lamination for paper of a certain weight are defined. Programs for definition of optimum parameters of lamination are developed. The obtained results give a possibility to automate the process of adjustment of a laminator.

3 CONCLUSION

It has been determined that lamination quality is influenced by regime and technology factors as follows: at the increase in temperature the strength of lamination increases, and, the thicker the paper, the greater should be the temperature of lamination. At the increase in speed the strength of lamination decreases. The increase in lamination temperature increases the laminate curling, and the increase in speed decreases the curling.

The analysis of values of factor of strengthening for different 'film-paper' systems has shown that their strength is greater than the total strength of the materials the system is made of. Besides, for a film-paper system the factor of strengthening in the longitudinal direction is close to one, while in cross-sectional makes 2.81, which testifies strengthening the system in the cross-sectional direction almost three times.

On the basis of the analysis of experimental data models for the description of strength of lamination and curling laminates, depending on the weight of paper, working speed and temperature are obtained. By means of the obtained models, conditions at which admissible working speeds and temperatures of lamination are defined for paper of given weight are established. The obtained mathematical model of lamination allows to establish an optimum mode of lamination for certain initial conditions, to simplify the process of choice of lamination parameters and to ensure high quality production at the maximum productivity and the minimum power input.

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