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Study of Physical Aspects of Electroflocking (Flock Printing)

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This paper analyzes the process of fibers transfer in an electrostatic field, degree of their orientation and arrangement density. Physico-mechanical properties of fibers and their influence on quality of the flocked images have been studied. Glue compositions have been selected on the base of polyvinylacetate (PVA). A mathematical model of the orientation of fibers in an electrostatic field is proposed. The scanning electron microscopy study confirmed fastening of the pile on a glue layer. A model test scale for determining the precision of flocked images and their sorting has been developed.
Keywords: electroflocking, paper, glue, flock, fiber, printed products, electrostatic field, quality.

1. INTRODUCTION

Flocked materials are produced by means of different technologies and the best known among them is “transfer” or “simple” printing (a pattern laid over special paper is transferred on the flocked substratum) and “wet printing”, which is imitation of velour with a laid over image by polychromate print dyes on the flocked substratum by a white colour flock (pile) [1, 2]. Making of a sample flocked image is an applique work of small natural or synthetic fibers in a form of a pattern (original) on the glue substratum [3].

The electroflocking method is well known in textile technology. However, many aspects of this process cannot be exactly transferred to the finishing printing technology. According to [4 – 8] the thorough examination of flocked material aiming at optimization of their properties can be done only by studying the structural indicators of the products. Then the basic elements of the structure are separated (in flocked materials they are pile, glue, and substratum) and the influence of these elements on the complex properties of materials (elasticity, strength, wear characteristics, physical properties) is examined.

In modern technologies flock image can be obtained electrostatically and mechanically on any materials (paper, cardboard, film, plastics). Irrespective of the method this process consists of the following operations:

1. Laying of the glue composition (glue on the base of PVA, carbide epoxy phenol resins, polyurethane, acryl emulsions and latex) on the surface-substratum through a stencil;
2. Flocking – process of distribution of a flock in a glue layer on the surface and substratum;
3. Removal of the flock remnants from the surface, which have not consolidated their hold;
4. Drying and fastening of a flock in a glue layer.

For the finishing process flocks are made of fibers such as cotton, nylon, kapron, polyester, rayon and etc. The whole gamut of colours of a flock is rather wide (over 30 colours) and their combination produces different shades [9, 10].

The basic distinction of the properties of flocked materials and properties of materials with pile of different appearance produced by mechanical technology methods lies in the oriented arrangement of fibers. Thus, the properties of pile coating (main quality indicator for similar materials) are determined by the orientation degree and suitable density of the fibers arrangement. The fibers orientation process can be considered as a consequence of the display of fibers physical properties when they are in electric field.

The influence of physical-mechanical properties of fibers on the quality of flocked images is of great importance. A special attention should be given to the vertical arrangement of fibers, when they are glue fastened, as it is to be taken into account in considering the pile wear. Electrophysical fiber properties, their charging process and behaviour in the electrostatic field may substantially vary with the change of air humidity. For this reason, the change of fibers properties by chemical treatment is to be carried out with a view of developing the stable fiber properties insensitive to the changes of atmosphere humidity. For this reason, the study of properties of materials and the influence of technological and operational factors on the electroflocking process in polygraphy have to be investigated both theoretically and experimentally.

This study aims to select the photopolymeric composition for producing a stencil intended for laying of glue pattern in compliance with the original image over the clean and laminated substratum; development of a test scale for testing of the quality of flock images; description of the process of moving the flock in the electrostatic field.

2. STUDY METHODS

The method of flocking by laying a flock “bottom up” in an electroflocking device was patented in Ukraine [11, 12]. To produce a glue pattern, the glue composition developed by the authors was used [13]. According to the suggested method, the flock images were obtained in the electrostatic field.

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In making stencils, applied for production of glue patterns on various paper, the liquid photopolymerisationable compositions on the base of MGF-9 (α,ω-methacryl (butylethylene glycol) phthalate) were used. In addition to MGF-9, the photopolymeric composition includes triethylene glycol – dimethacrylic – TGM-3 and photoinitiator dimethylhydroxideacetonephe-none (Darokur-1173). This copying layer is resistant to chemical reagents and provides the necessary depth of the glue layer.

The depth of a glue layer laid on a paper, penetration depth into its flock fibers under electrostatic coating and structure of pile coating were microscopically examined. Samples for the microscopic examination were made by the method of thin cross-cuts. They were fixed on a microtome perpendicular to the blade (inclination angle – 5 degrees), the cut depth was set 5 μm – 7 μm on the scale [14]. To ensure validity of the statistic data, 12 cuts of each examined sample were photographed and analyzed with a scanning electron microscope (SEM) "Olympus SZ-11".

When evaluating the prints obtained by polygraphic means, the estimation of flock images quality requires additional control of elements, which are not present in test-scales. A model test-scale has been developed to determine the precision of flock images and separating space (Fig. 1). The scale can predict the displacement of various pattern elements over the surface area. In addition to the strips of 0.02 cm – 0.3 cm width, triangles, starlets having 5 to 160 angles, circles of 0.2 cm – 1.2 cm diameter, squares and others were placed on a stencil. Introduction of geometrical shapes having different angles to the scale makes possible to determine durability of the flock images.

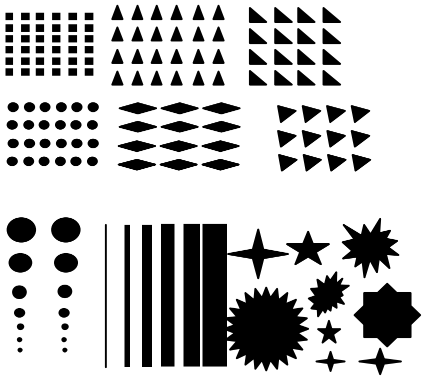

Fig. 1. Model test-scale

3. THEORY AND EXPERIMENTAL RESULTS OF ELECTROFLOCKING PROCESS

3.1. Theoretical consideration

The process of fibers displacement in electrostatic field is important not only to their travel from the bin to paper or film, but also to provision of a sufficient depth of fibers flock penetration into glue.

The linear momentum of fibers of mass m with a charge Q in the electrostatic field of intensity E can be expressed as follows [10]:

$$mv = \sqrt{2mhQE(1+\frac{gm}{qE})}\ , \qquad (1)$$

where v is the rate of displacement at distance h; g is the acceleration of free fall.

A salient feature of fibers orientation when laying the pile is that the final orientation in a glue layer depends on the distance between the electrodes, while the increase in the distance is limited by the ultimate voltage of the current source.

Let us assume that the flock brought to the field polarizes instantaneously thus causing the appearance of a dipole with balanced polarizing charges ($+q$, $-q$), the distance between them being equal to the fiber length l. Moreover, the fiber may have unbalanced charge Q, whose center shifts from the center of the fiber mass by value $0.5\ r\ l$, where ($-1 \le r \le 1$).

It may be assumed that the fibers oscillate against the field direction with a constant period irrespective of the initial angle of their emergence. It provides a simultaneous equilibrium position for all fibers ($\varphi = 0$), and the problem of optimal orientation reduces to the choice of the position of the specified surface for the flocked image formation when the following condition is fulfilled [15]:

$$\omega_0 t = \frac{\pi}{2}(2n+1)\ , \qquad (2)$$

where $n = 0, 1, 2, 3$; ω_0 is the angular frequency, rad/s.

The application of alternating electric fields makes it possible to increase the extent of the medium orientation of fibers if compared to the electrostatic field. Laying fibers over paper or film substratum in the alternating field provides the complete coating and eliminates emerging defects. Fibers can be charged when coming into a direct contact with an electrode or in a corona discharge zone (i. e. when ions settle down on the surface of flock fibers). The fiber may be charged when being in the corona for a definite time (so called relax time) [16]:

$$\tau = \varepsilon_0 \varepsilon_r \rho\ , \qquad (3)$$

where ρ is the resistivity of fiber, Ω; ε_0 is the dielectric constant; ε_r is the relative dielectric strength of fiber.

3.2. Experimental results and discussions

The scanning electron microscopy examination confirms the physical model on fastening the pile in a glue layer.

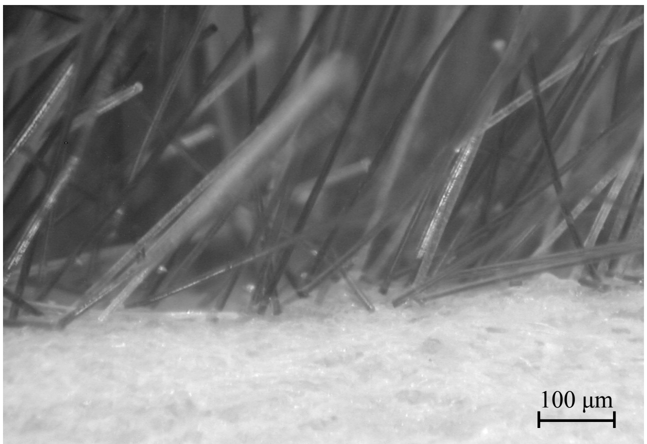

Fig. 2. The microphotograph of a flocked image laid by kapron pile over the paper surface

The analysis of microphotographs (Figs. 2 – 4) of flocked images laid by kapron pile over paper and paper covered by laminates using glue consisting of PVAD and polyurethane composition shows the orientation of fibers fastening in glue and the depth of their penetration.

According to the microphotographs, insufficient stiffness of kapron fibers larger than 3 mm and low density of coating cause an increase in a load on an individual fiber resulting in both an increase in strength of tension and reduction in adhesive bond between the pile and glue. The flock of 3 mm length possesses high stiffness, much thicker surface coating and high wear resistance.

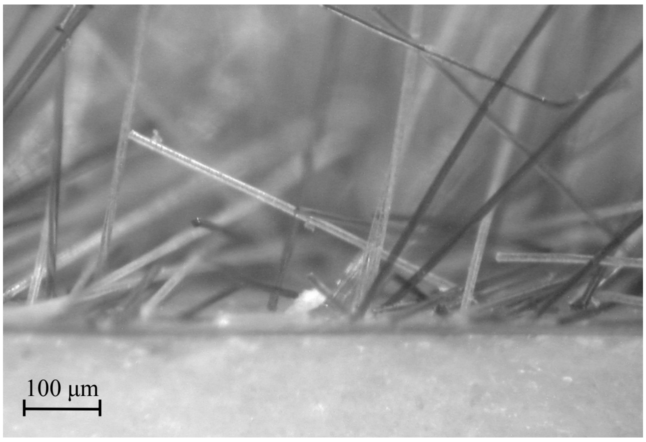

Fig. 3. The microphotograph of a flocked image laid by kapron pile over the surface of paper coated with laminates

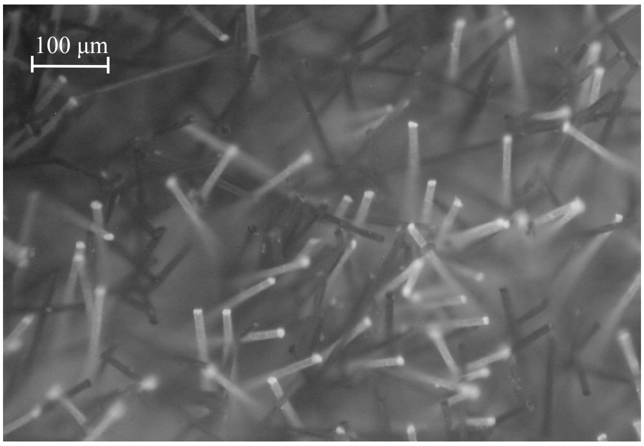

Fig. 4. Microphoto of a flocked image laid by kapron pile over the surface of paper (top view)

Furthermore, to fasten this flock a smaller depth of a glue layer is laid in comparison to the long pile. The SEM analysis confirms the statement of other investigators [5, 6] that at optimal flocking, which provides considerable strength to fastening, the pile penetrates glue by 1/3 to 1/10 of its own length.

Application of electric fields for laying the pile is intended for reaching high degree of orientation at the moment of its fastening in glue. All this results in maximal dense arrangement of fibers on the surface of paper or cardboard ensuring high quality of the product. Undoubtedly, the basic parameters characterizing the process of laying the pile in the electric fields are density of the pile and strength of fibers fastening. Therefore, the optimal choice of physico-mechanical regimes providing the maximum density of the pile is one among major tasks of this technology. The experiments were carried out at a frequency of electric field $f = 50$ Hz and an electric current $I = 0.1$ mA.

Density of fibers in the process of electroflocking is a function of time. When the fibers moving between the electrodes at the moment of being fastened in glue do not manage to orient themselves along the force lines of the field and take the vertical position with respect to the substratum then the fibers are fastened aslant.

Being inclined the fibers occupy more area, thus decreasing their probability when approaching the glue layer to find their “free space”. In this way they inhibit the ultimate strength of the pile fastening by reducing it.

With decrease in the inclination angle the pile density abruptly increases. A great density increase is noticed at small angles (less than 10°). The inclined arrangement of fibers is responsible for their being fastened in bunches. It happens when a fiber being fastened in glue at an angle is pushed by the other fiber, which while rushing in the substratum slips over it and is fastened at the base of the former fiber. It should be mentioned that durability of fastening in bunches is lower than that done with individual fibers [17].

The study of the strength to wear of flocked coatings depending on the characteristics of the electrostatic field has allowed to accomplish optimization of the electro-flocking process by the method of the least squares. This method enabled to provide the highest strength of fastening the flock in a glue layer. According to this method, the values of parameters a_i are determined on condition that deviation of the least values sum of the squares of the observed values of the strength to wear P from the model corresponding values is reached:

$$\sum_{j=1}^{n}\left(P_j - a_0 - a_1 U_j - a_2 l_j - a_3 U_j l_j - a_4 U_j^2 - a_5 l_j^2\right)^2 \to \min, \quad (4)$$

where n is the number of observation results; P_j is the value of coating strength to wear observed at the time of the j^{th} test at the distance between electrodes l_j and induced voltage. Due to the method of least squares the values of the model parameters are determined by means the Maple mathematical system. Taking into account the calculations the diagram of an electroflocking process model has been developed (Fig. 5).

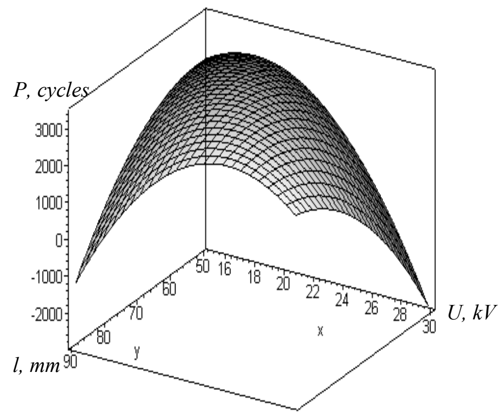

Fig. 5. Three-dimensional model of a flocking process

The set of equations for determining the optimal characteristics are:

$$\begin{cases} 731.27 + 14.29l - 79.51U = 0 \\ 61.14 + 14.29U - 5.18l = 0 \end{cases}. \quad (5)$$

The optimal values of voltage and distance between the electrodes are obtained: $U_o = 22.42$ kV; $l_o = 73.58$ mm. The corresponding values of the model at this point are equal to 3407.6 cycles.

CONCLUSIONS

1. Under the voltage of the electrostatic field $E = 3$ kV/cm – 4 kV/cm for a flock of 1 mm length the maximum density of the pile coating is (40 – 45) fibers/mm^2 with strength to wear up to 3275 cycles can be produced.
2. During the flocking process the pile penetrates glue at a distance of 1/3 to 1/10 of its length. Pile coating density depends on the orientation of fibers in the electrostatic field while, with an increase in the fibers inclination angle, it decreases
3. Electroflocking process has been optimized by means of mathematical modelling. Correlation between the technological and operational factors of the flocking process (voltage 22 kV, distance between electrodes 73 mm) has been studied and it was found to ensure the highest strength of the flock fastening.

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