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Development and Research of Technologies and Methods of Electroflocking in the Decoration of Packaging Products

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1. Introduction

Electroflocking technology creates textured surfaces and decorative effects on various materials. The application of natural or synthetic fibers to the surface of textiles is used to create velvety or "soft" coatings. Analyzing scientific publications, we find widespread application of this technology in the textile industry. A study [1] investigated thermal transfer films such as Flex and Flock, which are new decorative materials for textiles (used in fashion design, sportswear, corporate, and leisure wear). The author describes their structure, advantages, and the techniques employed in thermal transfer. Research [2] focused on eliminating defects related to the non-recovery of bent fibers in flocked coatings. It aimed to minimize their recovery time by optimizing selected process parameters in flocked fabric production.

Scientific work [3] focuses on developing a mathematical model of fiber movement in an electrostatic field. Flock processing parameters were experimentally measured and incorporated into the numerical solution of the model equations. This article [4] explores the multifaceted application of heat-exchange vinyl materials in design practice and provides information on their importance and influence in creative and industrial spheres. The authors [5] use the thinnest polyamide fiber for the production of pile fabric. To optimize the process parameters in terms of flocking density, they employed a full factorial design with three factors at three levels. The optimal parameters were determined both empirically and experimentally: a flocking distance of 7 cm, a field strength of 60 kV, and a flocking time of 10 s.

In recent years, studies have confirmed the use of electrostatic flocculation for biomedical applications [6–8], particularly in bone and skin tissue engineering, wound healing and treatment [6], and the development of new types of tissue engineering scaffolds [7, 8]. Studies [9–10] present the mechanical characteristics of flocked cardboard (breaking strength, stress, and deformation) along with electron microscopic analyses of its structure during the manufacturing of packaging products.

2. Problem Description and Formulation

Given today's trend toward smaller print runs, mass production of printed products is becoming less popular. Large, uniform editions are being replaced by unique, exclusive, and individualized copies. The most popular type of consumer packaging today is self-assembling boxes made of cardboard and microcorrugated cardboard, used primarily for non-food products and food items requiring special storage or transportation conditions. However, a truly memorable gift requires exclusive, elegant packaging that enhances its image and atmosphere. A notable example is packaging made of wood fiber materials (HDF, MDF, plywood), further refined using the electroflocking method.

The primary method for applying a flocked coating is single-color continuous or selective flocking technology. However, in printing, multi-color imaging technologies, including flocking, are of particular interest. The separation method is time-consuming and inefficient. Therefore, finding alternative approaches to creating multi-color images using electrostatic flocking in the production and decoration of printed products such as packaging, postcards, and book covers is a pressing challenge. Thus, this study aims to analyze modern electroflocking technology and develop a new method for printing color images on white flocked material.

3. Research Methods and Equipment

The image layout was designed using COREL DRAW software. HDF (High-Density Fiberboard) was selected as the packaging material. It is a wood-based modern material, considered a more advanced and sustainable alternative to traditional fiberboard. The HDF used in this study (KronoSpan, Poland) featured a painted white coating and had a thickness of 3 mm. Printing was performed using DTI InkTec sublimation inks on an Epson L132 inkjet printer, followed by image transfer with an Amazon MAX 400C thermal press. The printing was done on the 0.5 mm thick SEF FiberPlus thermal transfer sublimation flock film, which contains exclusive polyester microfibers and 100% polyurethane resins. The packaging components were cut using a TS1390 CO_2 laser cutter with a wavelength of 10.6 μm. Image quality was evaluated using operational control scales (Fig. 1).

4. Results and Discussion

Electrostatic flocking is a method of three-dimensional printing. It involves creating a high-strength flocked image on an adhesive base within a high-voltage electrostatic field, reaching hundreds of thousands of volts. The effective application of electrostatic flocking requires strict process control, specialized equipment, specific materials, and adherence to technological parameters.

This method is widely used in the textile industry, as well as in the production of jewelry, toys, packaging, and protective coatings for industrial electrical devices. The decorative and functional potential of flocked materials is illustrated in Fig. 2 [3, 11, 12].

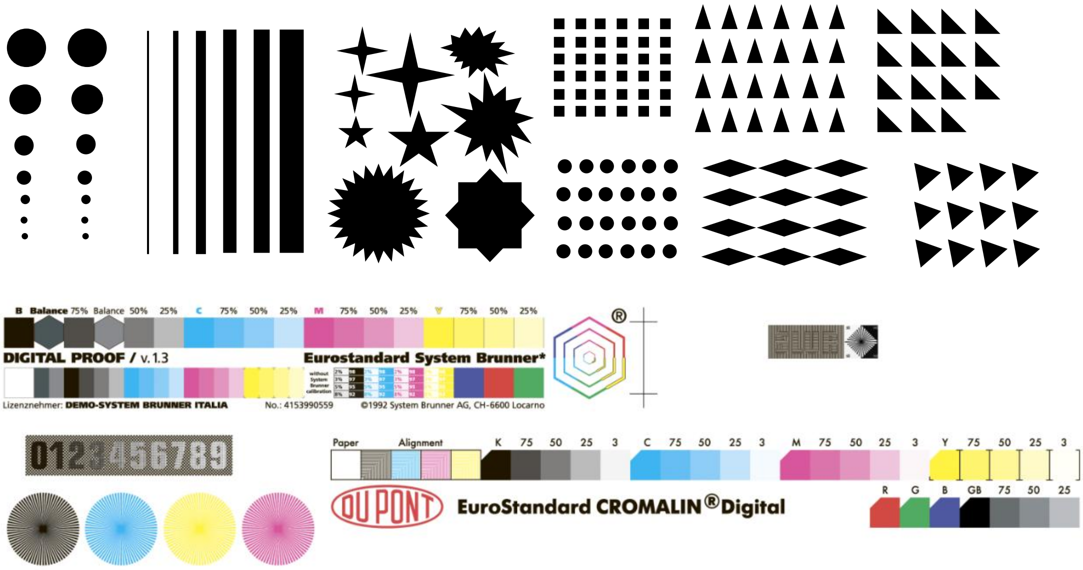


Fig. 1 Scales of operational control of image quality assessment when printing on flocked film

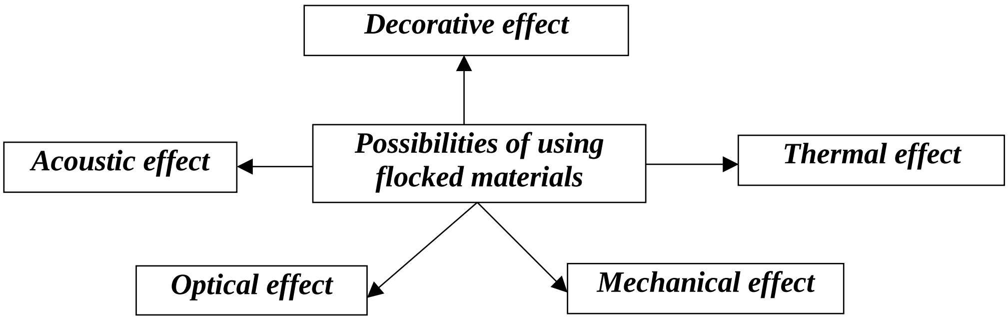


Fig. 2 Possibilities of using flocked materials from the point of view of decorativeness and functionality

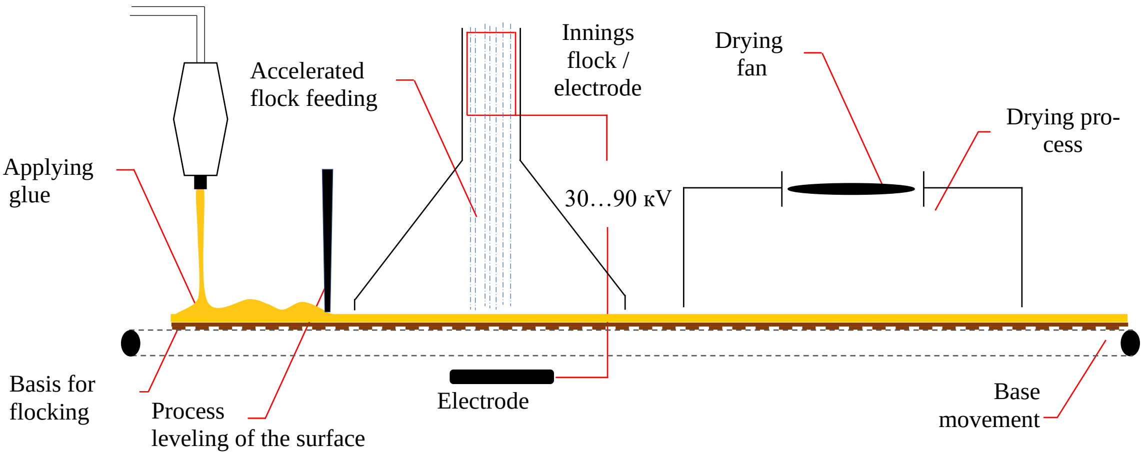


Fig. 3. General diagram of the electroflocking process

Properties of the flocked surface:

- Light resistance lasts approximately 5 years.
- High abrasion resistance – after 10,000 friction cycles, the mass loss is only 23 mg, compared to 732 mg for felt.
- The flocked surface enhances adhesion to other materials.
- Can be cleaned with standard detergents, including
- chemical ones, without color fading.
- Prevents condensation, is safe for health, and environmentally friendly.
- Poor flammability (ignition temperature varies from 400°C to 5500°C, depending on flock type).
- Effective thermal insulation – a 2 mm flock layer can replace 10 mm of polystyrene.
- Excellent sound insulation – a 2 mm flock layer reduces noise by 13 dB.
- When applied to contacting surfaces, a 2 mm flock layer fills gaps up to 4 mm and increases friction.
- Available in a wide range of colors.
- Soft and pleasant to the touch [3, 13].

Expanding the application of flocking technology and developing functional, high-tech products, such as souvenir and gift packaging, is a key direction for the electrostatic flocking industry at this stage.

Beyond fabrics, leather, and textiles, flocking is also applied to paper, cardboard, film, plastic, and wood-fiber materials for decoration and finishing. Polyamide is the most commonly used type of flock due to its wear and moisture resistance, non-flammability, ease of cleaning, and high resistance to washing and abrasion. If a product's surface is damaged, flocking can be applied to conceal the defect, protecting it from scratches and irregularities. The general process of electrostatic flocking is illustrated in Fig. 3 [14].

The recharging of fibers during their collision at the moment of fastening affects the pile density. Due to the low electrical conductivity of the pile, these collisions lead to fiber accumulation on the already fixed pile. As a result, more fibers settle in a nearly horizontal position, reducing the free surface area, slowing down adhesion, and potentially interrupting the process.

Electroflocking technologies are categorized into surface (flat) and three-dimensional applications. Manual flockers, equipped with a high-voltage electrode, are used for small-scale flocking. For low-volume flocking of complex-shaped bulky products, such as bottles, cans, and boxes, a chamber flocking device is used—a compact tabletop chamber. The flocking process is performed exclusively in a "top-down" manner. The product is fixed on a grounded rod with a reliable electrical connection. To increase productivity, additional electrodes tailored to specific product shapes can be integrated.

For small-volume production of flat products, adhesive application is done using a brush, tampon, roller, or squeegee with a manual screen printer (e.g., SPR-20 model). A solvent-based adhesive with a long open time is required. The flocking process is performed using a mini-flocker (e.g., MINI Flocker Evo and EASY Flocker), with a drying time of 24 hours at room temperature.

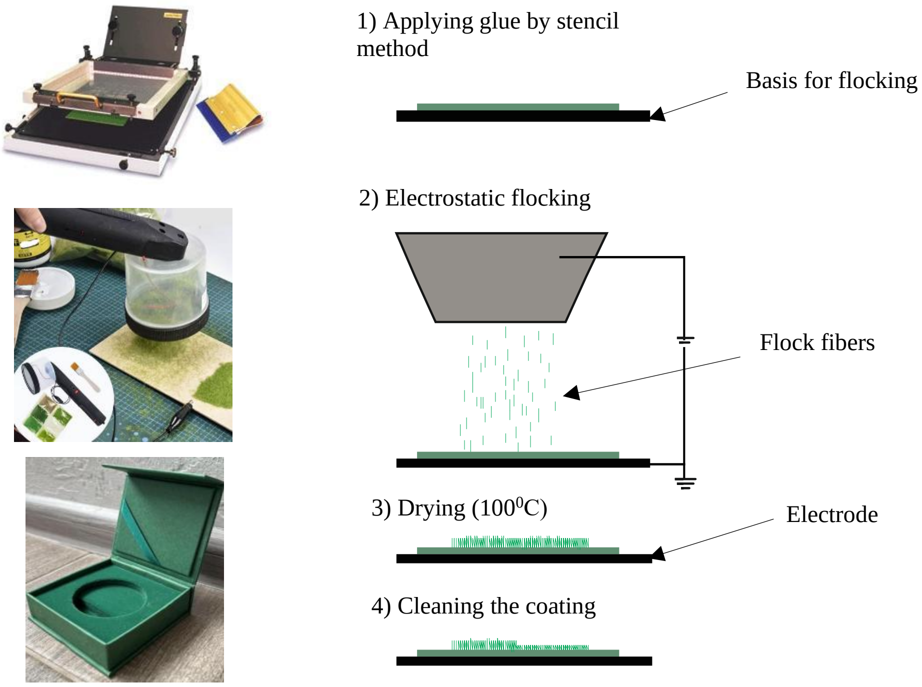


Fig. 4 The technological process of flocking using a manual flocker: 1 – applying glue to the surface of the product; 2 – applying an electric charge to the previously prepared flock and transferring it to the glued surface of the product; 3 – drying; 4 – suction of flock residue and removal with a brush

In medium and large-scale production, industrial flocking machines operate in assembly lines to process various parts, sheets, and roll materials. The chamber holds 6-8 kg of flock, and the flow rate is regulated by adjusting the brush rotation speed. A belt conveyor can be installed beneath the machine to enhance productivity. For medium-volume flocking of bulky products like bottles, the dipping method is also used for adhesive application, alongside the bead and tampon methods.

In mass production (e.g., souvenir and gift boxes), the following features of the flocking process are typically observed:

- The adhesive layer is mostly applied using water-based dispersion glue by spraying.
- A stationary flocking machine is employed for the flocking process.
- Drying occurs in a pass-through oven. The optimal distance between the flocking object and the hopper ranges from 50 to 300 mm [13].

Production equipment for flocking can vary widely, ranging from manual and chamber flockers for small businesses to automatic flocking lines for roll materials. Regardless of the scale of production, flocking equipment must ensure the execution of all basic flocking operations. An additional step, depending on the type of base and material used for flocking, may involve the application of a primer layer on the surface of the product. Fig. 4 shows the technological cycle of flocking.

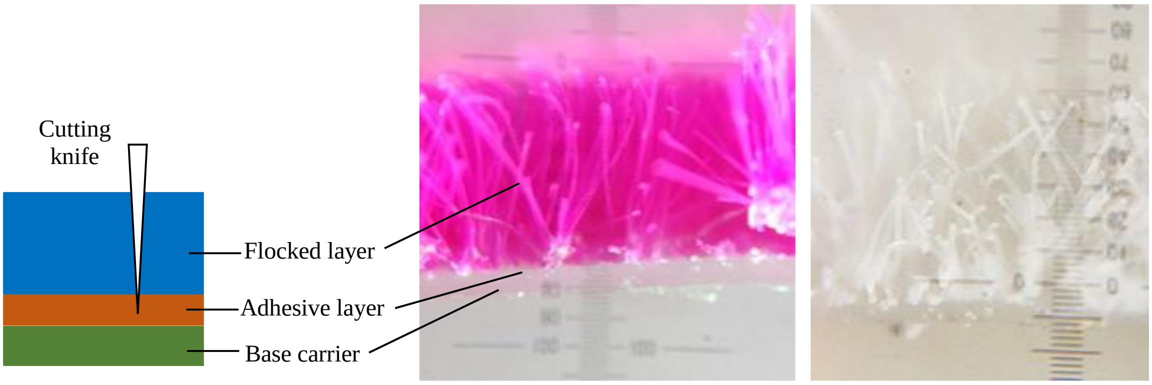
As mentioned earlier, a limitation of this technology is its ability to produce only monochrome images. Recently, thermal transfer flocked film (such as JETFLOCK, Poli-Tape TUBITHERM FLOCK, Siser STRIPFLOCK PRO, Forever Subli-Flock) has gained popularity. This film, available in sheets or rolls of various colors, is shown in Fig. 5.

a b

Fig. 5 Flocked thermal transfer film: a – sheet; b – roll

This material was tested for decorating HDF packages. During the research, a technological process for thermal transfer of images was developed, in which the printing process was carried out on white flock material using an inkjet printer with sublimation inks, followed by thermal transfer in a thermal press onto HDF (Fig. 7, a):

1. Print the image on flocked film in direct (non-mirror) reflection.
2. Cut the image along the contour according to the layout. Cutting can be done using a cutting device, cutting plotter, or laser machine (Fig. 6).
3. Remove unnecessary fragments and detach the image from the substrate (this can be done using thermal transfer mounting tape or manually).



a b c

d e

Fig. 6 Cutting the image along the contour according to the layout: a – the method of cutting with a plotter to the depth of the bearing layer; b – microphotograph of pink sublimation flock film (increase by 60 times); c – microphotographs of white sublimation flock film (increase by 60 times); d – cutting plotter Graphtec CE LITE-50; e – TS 1390 laser machine

4. Pre-steam the material or product in a heat press for about 3-5 seconds.
5. Position the image on the product in the thermopress with the mounting tape facing up. If the image was separated from the substrate without the use of mounting film, cover (protect) the image with Teflon or parchment paper or use the same base substrate from which the image was removed.
6. Perform thermal transfer in a thermal press using the following settings: transfer temperature of 170°C, transfer time of 40 seconds, and medium pressure (3.0 bar).
7. Remove the product from the thermopress.
8. Separate the mounting film or substrate from the image.

In the second method (Fig. 7, b), a combined method for printing a photograph was performed using intermediate thermal transfer paper with sublimation inks, followed by the transfer of the image to HDF material in a thermal press. Then, according to the layout, a heart-shaped image was cut on the flocked material using a laser machine and fixed onto the package lid in a thermo press. This method allows for the combination of multiple cut-out images from the flocked material of various shapes and colors, giving the package an attractive velvet appearance.

The quality of the printed image using sublimation inks on HDF and white flocked material was evaluated through densitometric studies (Fig. 8, Table 1).

From the obtained graphical dependencies (Fig. 10), it can be observed that the optical density of the printed image fields with sublimation inks transferred to HDF is approximately 40-50% higher than the image obtained on white flocked material. The decrease in optical density can be attributed to the high porosity of the flocked material; however, the image still appears visually contrasty and saturated. The highest optical density value is observed for black ink, with densities of 2.41 on HDF and 1.43 on the flocked material, respectively, at a die density of 100%.

a b

Fig. 7 Image printing and thermal transfer in a thermal press: a – printed image on white flocked material; b – printing on HDF, cutting on a laser engraver and thermal transfer in a thermal press

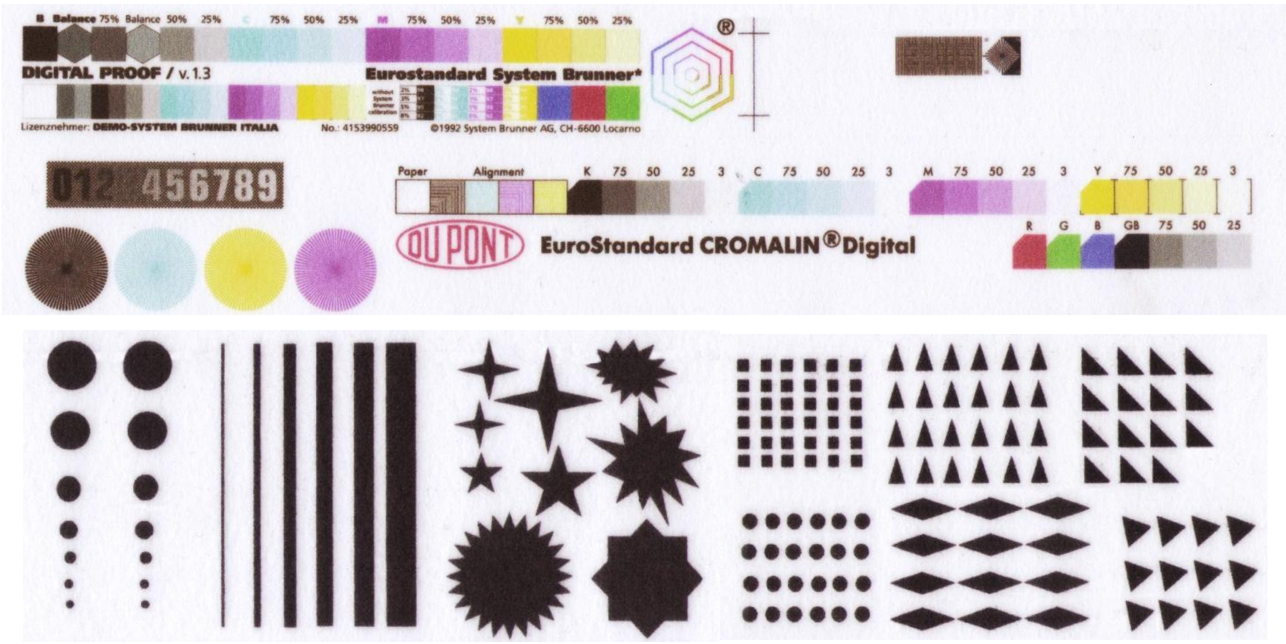
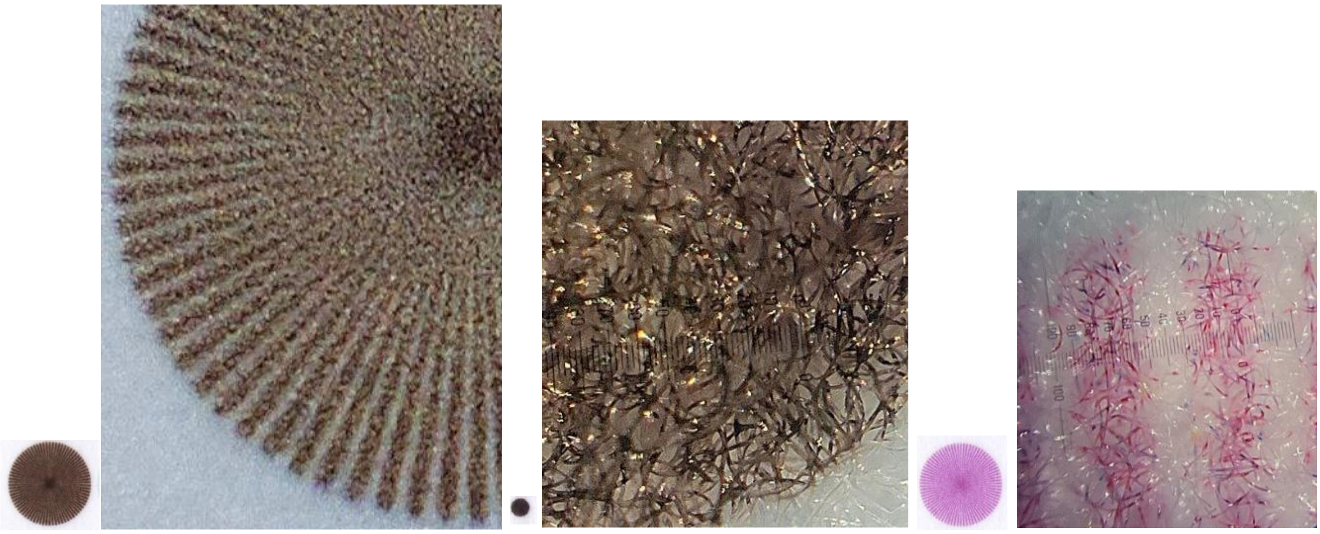


Fig. 8 Scales of operational control of image quality assessment, printed on flocked film

Table 1

Values of optical densities of fields of printed images on HDF and flocked material

Imprint	Optical density, *D*			
	blue	purple	yellow	black
Thermal image transfer on HDF die density				
100 %	0,95	1,21	2,08	2,41
75 %	0,79	0,88	1,78	1,9
50 %	0,59	0,63	1,05	1,14
25 %	0,3	0,33	0,55	0,5
Printing on white flocked material and fixing the image in a heat press die density				
100 %	0,54	0,94	1,13	1,43
75 %	0,47	0,8	0,86	1,09
50 %	0,33	0,55	0,61	1,10
25 %	0,18	0,29	0,30	0,67



a b c d e f

Fig. 9 Electron microscopic photographs of the printed image on flocked film: a, c, e – actual image size, b – magnified 20 times, d – magnified 60 times; f – magnified 30 times

Electron microscopic studies of the printed image on flocked film using a Yashima Tokyo 60x microscope (Fig. 9) have shown that the fibers are arranged chaotically. The image on the flocked film is printed using the sublimation method with the resolution of the printer. During further fixation in a heat press under the load of the upper plate, the orientation of the fibers changes, making the uncolored fibers more visible, which leads to a decrease in the optical density of the image.

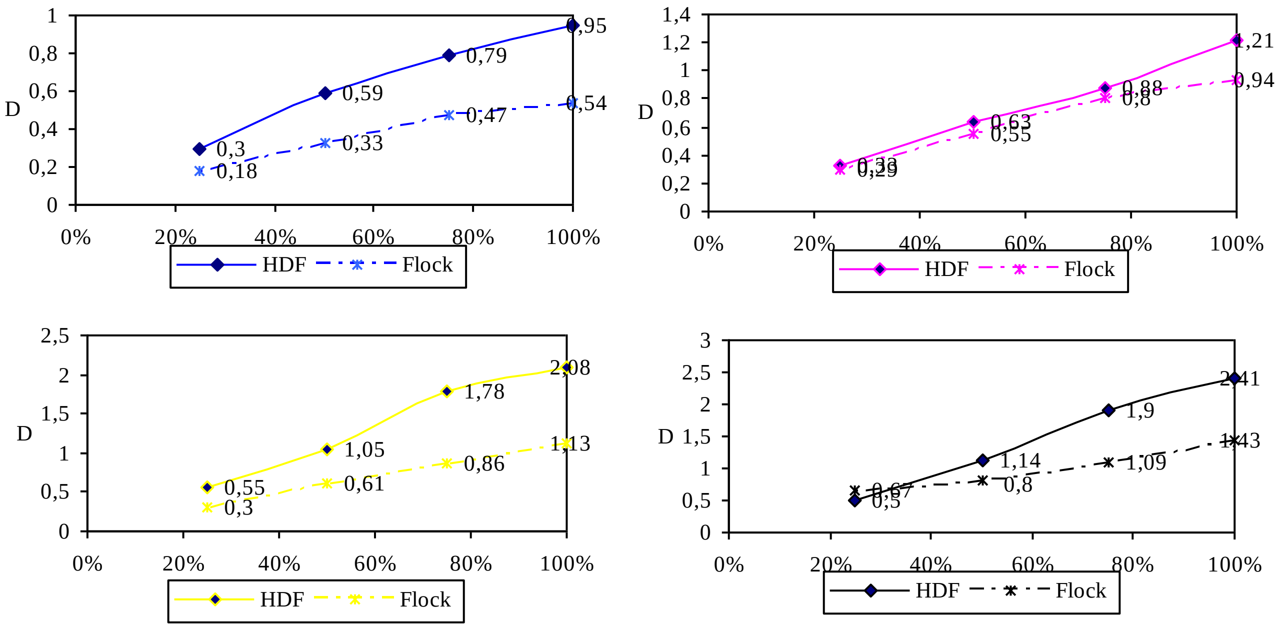


Fig. 10 The value of the optical densities of the fields with thermal transfer of the image on HDF and with printing on white flocked material in colors: a – blue; b – purple; c – yellow; d – black

5. Conclusions

This paper analyzes modern electroflocking technologies and introduces a new method for printing color images on white flocked material, alongside the development of a technological process. This technology offers an alternative approach to decorating packages made of HDF wood-fibrous materials, providing them with an attractive velvet finish. The direct (non-mirrored) image printing was carried out on the 0.5 mm thick SEF FiberPlus thermal transfer sublimation flock film. The image fixation in the thermal press was achieved using the following parameters: transfer temperature of 170°C, thermal transfer time of 40 seconds, and pressure of 3.0 bar. The second method successfully combines indirect sublimation printing on HDF with the cutting of images from flocked materials in various geometric shapes and colors, which are then fixed in a heat press. Further research will focus on identifying different thermal transfer modes, which could significantly influence the quality of the printed image.

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DEVELOPMENT AND RESEARCH OF TECHNOLOGIES AND METHODS OF ELECTROFLOCKING IN THE DECORATION OF PACKAGING PRODUCTS

S u m m a r y

The aim of this work is to analyze the modern electroflocking technology and to develop a new method for printing a color image on white flocked material. For packaging material, High Density Fiberboard (HDF) with a 3 mm thick white painted coating was chosen. Printing was carried out using DTI InkTec sublimation inks on an Epson L132 inkjet printer, followed by image transfer in an Amazon MAX 400C heat press. The image was applied to a 0.5 mm thick SEF FiberPlus thermal transfer sublimation flock film, which contains exclusive polyester microfibers and 100% polyurethane resins. Cutting of the packaging components was performed using a TS1390 CO_2 laser cutting machine with a wavelength of 10.6 µm. Image quality was evaluated using operational control scales. Microscopic photographs were taken at 60x magnification. Image fixation in the heat press was done using the following parameters: transfer temperature 170°C, transfer time 40 seconds, and pressure 3.0 bar. As shown by microscopic studies, the reason for the reduced optical density of the printed image with sublimation inks on flocked film is its high porosity. Therefore, to enhance the decorative effect and give the packaging an attractive velvety appearance, it is advisable to use a combination of printing on flocked material with cutting out several differently shaped and colored images from the flocked material.

Keywords: electrostatic flocking, flock, HDF, sublimation flocked film, packaging, optical density, printing products.

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