UV-Curable Coating Process on CMYK-Printed Duplex Paperboard, Part I: Mechanical and Optical Properties

Mojtaba Soltani,[a,]* Ramin Veisi,[a] Ali Asghar Rohani,[a] Omid Ramzani,[b] Hamid Reza Naji,[c] and Edi Suhaimi Bakar [c]

An ultraviolet (UV)-curable coating is one of the best finishing methods in the paper and packaging industries for protecting ink layers from physical and mechanical defects. The purpose of this study was to investigate the mechanical and optical properties of CMYK printed paperboard after coating it with the UV-curable varnish. Commercial duplex paperboard (glazed grayback paperboard, 230 g/m^2) was printed with a CMYK offset printing process. After conditioning the printed samples, they were coated with a commercial UV-curable varnish (consisting of a liquor-to-solvent ratio of 50:50) using an industrial screen-coating machine. The samples were then dried using a UV lamp in an industrial UV drying machine. The discoloration of the CMYK ink layers was measured spectrophotometrically using CIELab parameters (L^*, a^*, b^*, and ΔE) before and after the coating process. The whiteness, brightness, and fold and tear resistance of the ink films were also measured. Color change (ΔE) was recorded for all tested samples, and the least amount of discoloration was observed in CYAN ink. The highest variances of the relative optical parameters were found in the MAGENTA, YELLOW, and BLACK ink films, which resulted in yellowing of the coated paperboard. It can therefore be concluded that the coating process significantly decreased the fold and tear resistance of the samples.

Keywords: UV-curable coating; Offset CMYK inks; Color measurement; Duplex paperboard; Mechanical properties

Contact information: a: Department of Wood and Paper Science and Technology, Islamic Azad University, Chalous Branch, P. O. Box 46615/397, Mazandaran, Iran; b: Department of Cellulose and Paper Technology, Shahid Beheshti University, Science and Research Park, Zirab campus, Zirab, Iran; c: Faculty of Forestry, Universiti Putra Malaysia, 43400, Serdang, Selangor, Malaysia.
**Corresponding author: soltani_iau@yahoo.com*

INTRODUCTION

Physical surface treatments, especially coating processes, are usually used to produce papers with better resistance to moisture or water penetration and mechanical scratch (Abdullah *et al.* 2013). Coating treatment is a common process in the printing and packaging industries and is used to address several problems, such as UV degradation and mechanical defects. In addition, the treatment improves other critical properties of paper, paperboard, and wood, such as optical properties (Vlad *et al.* 2009; Schwalm 2006).

Ultraviolet (UV)-curable coatings are mostly utilized in those industrial applications for which thermal curing is hardly possible (Schwalm 2006). UV-curable varnishes have some advantages including easy and wide-range applications, no emission of volatile organic compounds (VOC), excellent mechanical properties (especially abrasion and scratch resistance), and good optical properties, such as gloss. In contrast, some disadvantages of this coating process are increased oxygen sensitivity, higher water surface tension, and a higher price compared to other coaters, thereby limiting its utilization (Blanchard *et al.* 2009; Schwalm 2006). The mechanical properties related to folding are a crucial factor for the performance of paperboard used for packaging (Coffin *et al.* 2011). Before using the coaters, the printing process normally is the first step of the packaging. The CMYK color model is a subtractive primary color model that is commonly used in the color printing process (Almutawa and Moon 1999). The CMYK color model is based on four inks: CYAN, MAGENTA, YELLOW, and BLACK (see Appendix 1).

A combination of the aging effects of moisture and temperature was found to significantly reduce the density of the MAGENTA and YELLOW ink layers in the CMYK printing process. Additionally, the variance in total color difference ΔE (CIE $L^*a^*b^*$) of ink films evidenced the considerable damage of CYAN and YELLOW ink films (Havlínová *et al.* 2002).

However, UV-curable varnishes are commonly used to give a high gloss and rub-resistance to paperboard in the CMYK printing process (Karlović *et al.* 2010), but changes in the paperboard's optical properties and its foldability and tear resistance may be related to this coating process. Based on the best knowledge of the authors, the foldability and tear resistance of the paper boards were recognized as the main problem during the different steps of the finishing process, including printing, coating, and packaging. Therefore, the purpose of this study was to describe the effects of the UV-curable varnish on the optical and mechanical properties of coated-printed paperboard.

EXPERIMENTAL

Materials and Methods

A commercial glazed duplex paperboard (230 g/m^2, Hansol, Korea) was used as the substrate layer for these experiments. A CMYK test pattern in the machine direction was printed on the top side of the paperboard (Fig. 1) according to ISO 12647-2:2004, using a one-unit offset press (GTO–Heidelberg, Germany). The ideal inking parameters were adjusted using the same standard offset ink set (Saphira Ink C standard 100, Heidelberg, Germany).

Fig. 1. Printing-test pattern by CMYK printing method

The printed paperboard was room-conditioned at 22 ± 3 °C and 65% relative humidity (RH) for 24 h. The coating was then applied using an industrial screen coating machine (TMC, China). A commercial acrylic-based UV-curable glossy varnish (UV-LACQUER-FG.01, Laner, Turkey) was used for the coating step. The coatings were done by using a screen stencil of 180 threads/cm. Prior to coating, liquor was diluted with Vinyl ethers (a 50:50 ratio) to adjust the application viscosity. The solution was then applied to the printed sides of the paperboard along the machine direction.

The coated papers were then dried using a standard UV lamp (300 Watt/inch; UV wavelength: 350 to 420 nm) in an industrial UV-drying machine (TMC, China). Finally, the printed coated paperboard was room conditioned (Butkinaree *et al.* 2008). The coated printed paperboards were measured for tear and fold resistance, as well as optical properties. Each measurement was executed in exactly the same direction. Optical characterization of the printed substrates focused on obtaining spectral data (Borbély 2010).

For optical properties, the CIELab (L^*, a^*, and b^*) color parameters were computed in accordance with the TAPPI Standard (T524-om-02). Here, L^* refers to the lightness (from 0 to 100), a^* refers to the redness (from -60 to 60), and b^* refers to the yellowness (from - 60 to 60) of the specimens. The differences in the lightness (ΔL^*) and chroma coordinates (Δa^* and Δb^*) between the uncoated and coated specimens were calculated using the following formulas,

$$\Delta L^* = L^*_C - L^*_{Un} \tag{1}$$

$$\Delta a^* = a^*_C - a^*_{Un} \tag{2}$$

$$\Delta b^* = b^*_C - b^*_{Un} \tag{3}$$

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2} \tag{4}$$

where L^*_c, a^*_c, and b^*_c are the corresponding values of the coated specimens, and L^*_{Un}, a^*_{Un}, and b^*_{Un} are those of the uncoated specimens.

The brightness and whiteness of the paper specimens were also measured according to the TAPPI standards T452-om-92 and T462-om-05, respectively. Further, the folding and tear measurements were also performed in accordance with the TAPPI standards T511-om-02 and T414-om-98, respectively.

The statistical analyses for the mean differences in all treatments were tested using the Statistical Package for Social Science (SPSS® statistics processor, version 15) for Windows. The data were subjected to an analysis of variance procedure to examine the variability in the various properties. The Duncan multiple range test was used to separate the means of the various parameters at a 5% probability.

RESULTS AND DISCUSSION

Mechanical Properties

The mechanical properties related to tear and fold resistance are crucial for the performance of paperboard, especially in the process of converting it in the packaging process, where it may be affected by the coating. The application of the coating method resulted in the significant changes in the fold and tear values (see Fig. 2).

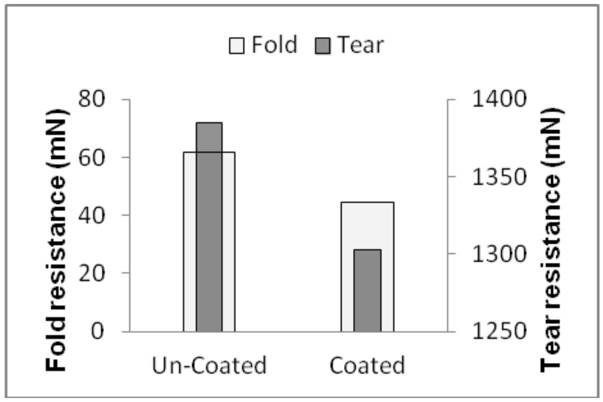

Fig. 2. Effect of UV-curable coater on the fold and tear resistances

Significant reductions in tear and fold resistances were demonstrated between the coated and uncoated paperboard (Fig. 2). The differences may be due to the increase in stiffness of the composite during the coating process as the application of coating reduces the flexibility of the paperboard and makes it somewhat brittle. However, this was expected according to the field observations. A UV-curable coating may increase the paperboard's resistance to rubbing and scratching, but it increases the stiffness and brittleness of the paper (Coffin *et al*. 2011).

Optical Properties

Significant changes in the optical parameters of the CMYK printed paperboard after the UV-curable coating was applied were noted (Fig. 3).

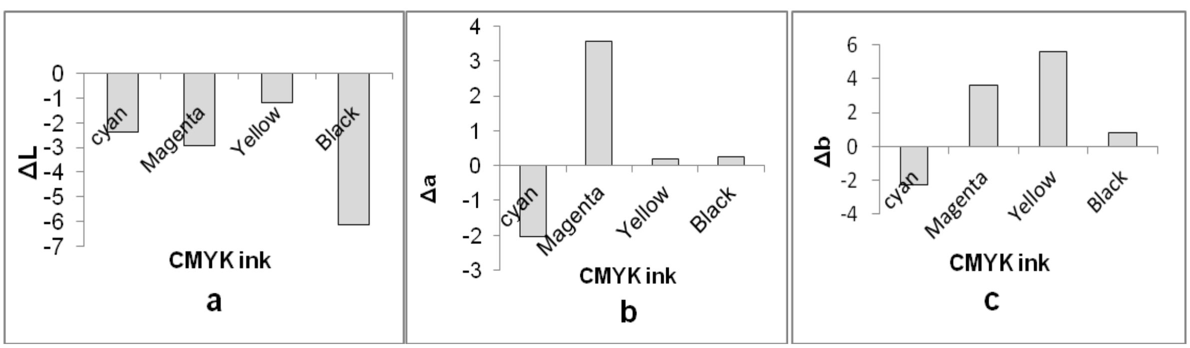

Fig. 3. The differences of color parameters of CMYK inks on coated paperboard

The differences in L^* values (ΔL^*) monitored upon coating for ink films on the paperboard were significantly decreased for all of the ink films; however, an exponential reduction was seen for the MAGENTA and the BLACK inks. In particular, the coating process darkened the CMYK offset ink films compared to the uncoated paperboard with more visible influences on the MAGENTA and BLACK ink films (Fig. 3a).

The values of Δa indicated a significant change in the MAGENTA and CYAN ink films after the coating process. In contrast, the coating process showed an insignificant change for the Δa value of the YELLOW and BLACK inks. In other words, the redness of the CYAN and MAGENTA inks were severely decreased and increased by coating the process, respectively (Fig. 3b).

The yellowness of the printed paperboard was compared by noting the Δb^* of the coated and uncoated paperboard (Fig. 3c). The increase of Δb of MAGENTA and YELLOW inks clearly indicated the significant increase of yellowness in the printed coated paperboard, while the yellowness of BLACK ink film negligibly increased. However, this index significantly decreased in the CYAN ink film, which is similar to the previous color parameters. This indicates that the optical parameters of the CMYK inks were affected by the coating process; however, the CYAN ink showed less change than the others.

In addition, the whiteness and brightness indices of the samples indicated that the coating process can noticeably improve CYAN ink reflection (Fig. 4). The whiteness of the CMYK ink films decreased in the MAGENTA, YELLOW, and BLACK inks after the coating, while the coating process increased the whiteness of the CYAN ink. In addition, the UV-cure coater decreased the brightness of the CMYK ink on the printed coated paperboard, as shown in Fig. 4.

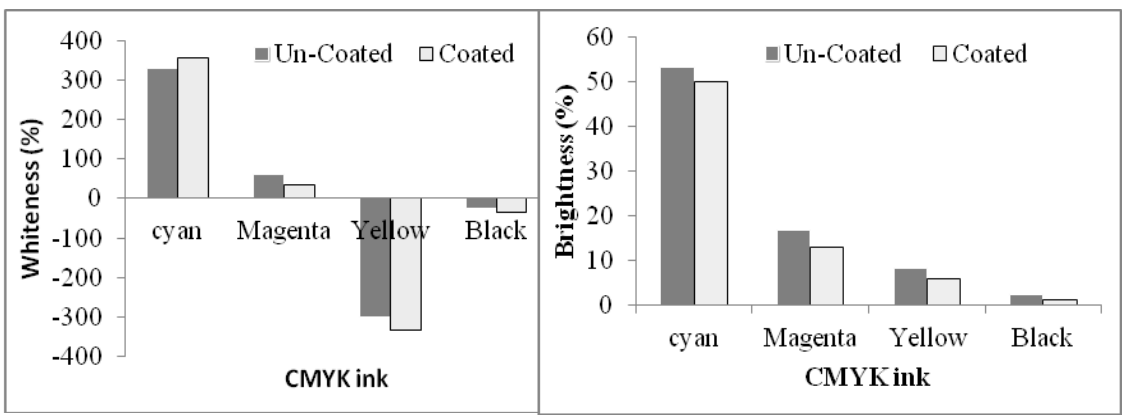

Fig. 4. The whiteness and brightness of CMYK inks on coated paperboard

These results show that the CYAN ink has a higher brightening value compared to other inks (Fig. 4), although a decreasing trend was observed from CYAN to BLACK in the CMYK ink films.

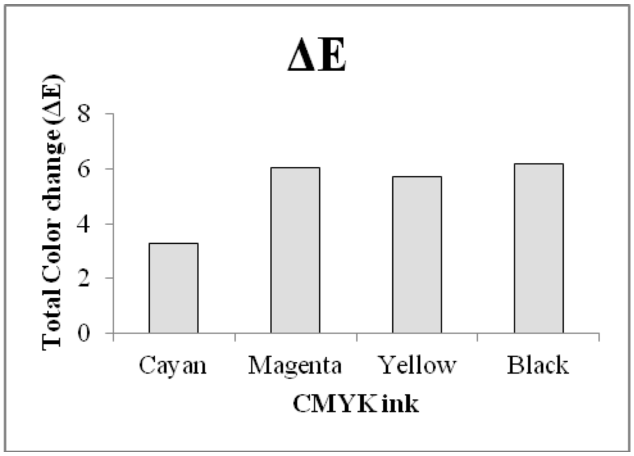

Fig. 5. Total color changes (Δ*E*) of CMYK inks on coated paperboard

The total color differences (Δ*E*) of coated and uncoated samples are presented in Fig. 5. When summarizing the total color differences (Δ*E*) measured for the CMYK offset inks, it should be noted that the most stability was observed for CYAN (Δ*E*<4) and the least was seen in the YELLOW (Δ*E*<6) ink (Havlinova *et al.* 2002). On the other hand, the MAGENTA and the BLACK inks had total color differences higher than 6, which correspond to the significant changes in these colors during the coating process (Fig. 4).

CONCLUSIONS

The UV-curable coating process was applied to the printed paperboard, and its effect on the mechanical properties and the optical stability of paperboard that had undergone a CMYK printing process was investigated. The findings were as follows:

1- A significant reduction was observed in the fold and tear resistances of the printed coated paperboard.

2- The UV-curable coater tangibly changed the ink reflection from light to dark. Likewise, the highest variances in the relative optical parameters were observed for the MAGENTA, YELLOW, and BLACK ink and resulted in a yellowing of the coated paperboard.

3- Except for the CYAN ink, the whiteness of the other inks was reduced by the coating. In addition, the brightness of the inks on the printed paperboard was also decreased. In contrast, the variations in total color difference (ΔE-$L^*a^*b^*$) evidenced a considerable stability of the CYAN ink.

APPENDIX

Offset lithographic printing is the most widely used commercial printing process for producing high-quality images in the printing and packaging industries and is used for posters, magazines, *etc.* In a CMYK printing system, which is the usual offset printing model, the combined effect of the four inks achieves the full spectrum of colors. The four ink colors are CYAN, MAGENTA, YELLOW, and KEY. The "K" in CMYK stands for *the key* because in four-color printing, cyan, magenta, and yellow printing plates are carefully *keyed*, or aligned, with the *key* of the BLACK Key Plate. The use of a separate BLACK ink is economical when a lot of BLACK ink will be used, such as in text media; this reduces the simultaneous use of the three colored inks. On the other hand, a fourth BLACK is added to improve the reproduction of some dark colors. This is called the "CMY" or "CMYK" color printing model (Almutawa 1999; Bergman 2005).

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