Investigation on differences in peel strength of the printed laminated paperboard

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Lamination process is one of the major surface enhancement techniques for print protection against mechanical surface damage, such as rubbing, tearing, scratching. Thus, the lamination process and its quality control are an active field of research, because it is significant for overall printed product quality assurance. The aim of the study is to investigate the differences in adhesive bond strength, i.e. peel strength of laminated printed sheets, depending on the used laminating film, printing color and employed digital printing machine tested via 180° peel adhesion testing. The samples were made from matte coated paperboard, printed by three different digital printing machines in full tone with the four process colors and laminated with two different polymer films (matte and gloss). The obtained results showed differences in peel strength caused not only by printing machine but also by laminating film, while a comprehensive statistical analysis proved that ink color had only partially influence on overall peel strength of laminated samples.

Keywords: peel strength, laminated paperboard, digital printing

INTRODUCTION

The lamination process, as one of the main surface enhancement techniques in the printing industry, is providing protection against stains, smudges and spills, fingerprints, grease, dirt, moisture or mechanical surface damage by applying a thin layer of polymer to paper or paperboard sheets. In general, lamination can be applied by heat or adhesion. Since the thermal application can provide a stronger and more durable bond than adhesion lamination, it is the most commonly used technique [1-3]. Lamination adds strength and stiffness to the printed substrates, improves their visual appearance by deepening and brightening the ink colors, making the printed images stand out more, while it does not impair or blemish the printing in any way. In addition, the lamination process is highly recommended for printed products with frequent use (for example: educational materials, book and brochure covers, business and membership cards, etc.). It increases the durability and protection from the wear and tear of everyday practices, such as creasing, tearing, scratching or sun damage, so they can withstand high levels of daily use [3, 4]. Other printed materials (such as operating instructions, safety signage, reusable tags, etc.), which have to be completely protected against dirt or moisture in damp or similar environment, usually get that laminating polymer film on both sides. The applied polymer films then often extended beyond the edge of the substrate, where the films can bond with each other. Thereby the printed substrate becomes totally enclosed in the polymer film, providing in that way, a tight seal which protects the printed material from dirt, moisture and other contaminants [5]. There are two basic types of thermal lamination foils, matte and gloss, but nowadays a new type of adaptable, silky finish foil is also present on the market. Along the proper protection, all these foils provide clear covering and make the printed text and illustration completely visible. However, due to the differences in the light reflection (matte foils absorb light, while gloss foils reflect it, and the silky ones are somewhere between them), these foils give different appearances to the printed substrates, so they should be selected accordingly to the required final look [4, 6]. Regardless of their surface characteristics, in general, thermal laminating foils are similarly constructed of a layer of the base film (polyester, nylon, polypropylene, vinyl, etc.) that is bonded to an adhesive layer [6].

The lamination process has been widely used on a broad range of substrates printed with conventional printing techniques (offset, rotogravure or flexography), but with the growing digital printing market, it is gaining importance in that field too, especially for the short-run high-quality graphic products. Digital printing technologies are increasing in popularity, mostly because of their effectiveness in short-run jobs at low costs and easy operational process. Electrophotography printing is one of the major digital printing technologies today, often called laser printing, since it is based on

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electrostatic charges on photoconductor drum caused by a light source, most commonly a laser.

In this printing technique the inks are toner-based and after the creation of latent image on photoconductor drum, the image is transferred and permanently fixed to the surface of the substrate using heat and pressure mechanism (hot roll fuser) or radiant fusing technology (oven fuser). This way they melt and bond the toner particles into the printing substrate. The derived printing quality is excellent and in order to extend the image life on printed products, especially with frequent use, the lamination process is applied [3, 7-10].

When it comes to quality of lamination, good adhesion is a prime consideration. Adhesion strength or bond strength is one of the main properties of a laminate structure, and its quality assessment is mandatory, because a laminated film, which does not adhere to the printed substrate has no commercial value [11]. The peel test is a commonly used testing method for objective evaluation of adhesion strength or bond strength in thin and flexible laminates or flexible-bonded-to rigid specimen. In general, the procedure consists of a laminate bonded to a thick substrate (or another laminate) and the test is conducted by pulling the laminate off of the substrate at defined angle while recording the peeling force during debonding. It is usually performed on tensile testing machines in several different ways using various commercially available fixtures [12].

The adhesion strength between lamination film and printed materials is influenced by factors related to the printing process, such as printing method, the type of color, the amount of applied ink, and factors related to the lamination process and conditions, such as temperature, speed or nip pressure [11]. While, the factors of lamination process could be adjusted to the certain printed project based on the foil manufacturer's` recommendation, factors of printing process heavily depend on graphic design, selected substrate, printing technique, etc. which are related to a given product type.

In this light, an investigation was done on the adhesive bond strength (peel strength) of two laminating foils adhered to substrate printed with three different digital printing machines in full tone of the four process colors. The conducted research was aiming to explore the changes in adhesive bond strength of applied laminating foils depending on the ink color and the employed digital printing system, and the results are presented in this paper.

Materials and methods

For the purpose of this investigation, a commercially available, matte, double side coated paperboard has been chosen (NEVIA CS2 Art Board, Hainan Jinhai Pulp & Paper Co, China) with basis weight of 300 g/m^2. The selected paperboard is commonly used for fine printed products such as book and magazine covers, advertising materials, calendars, catalogues, postcards, etc. Its dimensional stability, surface properties and good ink absorption allow trouble-free printing not just with conventional printing techniques (offset, rotogravure, flexography, letterpress), but with digital printing techniques as well. The basic properties of selected paperboard are presented in Table 1 [13].

Table 1. Basic properties of selected paperboard

Parameter	Value
Basis weight [g/m^2]	300±9
Thickness [µm]	285±8
Roughness [µm]	≤2.5
Gloss [%]	30±5
Opacity [%]	98.5±1.5
Brightness [%]	89.5±1.5

For the laminating process a gloss and a silky matte thermal laminating foil was selected from the same manufacturer (Cosmo Films Limited, India). Both foils are BOPP based and have extrusion coated surfaces with low temperature melting resin, which enables the lamination of the film to paper products by heat and pressure. They are applicable with all kinds of printed and unprinted paper and paperboards like book covers, magazines, diaries, brochures, manuals, folders, photo albums etc. Their basic characteristics are given in Table 2 [14,15].

Table 2. Basic properties of selected thermal gloss and matte foils

Properties	BOPP Gloss	BOPP Matte
Product reference number	24 PCT-2(DL)	27 PCT-2(M-SIL) DL
Thickness [µm]	24	27
Unit weight [g/m^2]	22	22.5
Yield [m^2/kg]	45.4	44.4
Surface tension (min.) Ex-coated/Uncoated side [dynes/cm]	42/38	40/40
Gloss (45°) - Uncoated side [gardner]	>58	17-25
Lamination temperature [°C]	100 - 120	100 - 120

In order to investigate the effect of different printing machines, colors and foil types on the peel strength (bond strength) of laminated paperboard, a simple test form was prepared based on [11]. It included a blank, non-printed area, used as a referent area with no color (0%) and four printed patches covered in maximum density for each primary process color (100% C, 100% M, 100% Y i 100% K). The dimensions of printed and non-printed areas were determined based on the specimen`s parameters defined by FINAT standard FTM 1 Peel adhesion (180°) at 300 mm per minute [16]. It defines a 25 mm wide specimen with a minimum length of 175 mm in the direction of traction displacement. The dimensions of a single specimen and the design of complete test form are presented on Figure 1. Printing of the prepared test form was done on the following three digital printing machines: Xerox DocuColor 252 (hereafter referred to as Machine 1 or M1), Xerox Versant 80 (Machine 2 or M2), Konica Minolta C6000L (Machine 3 or M3).

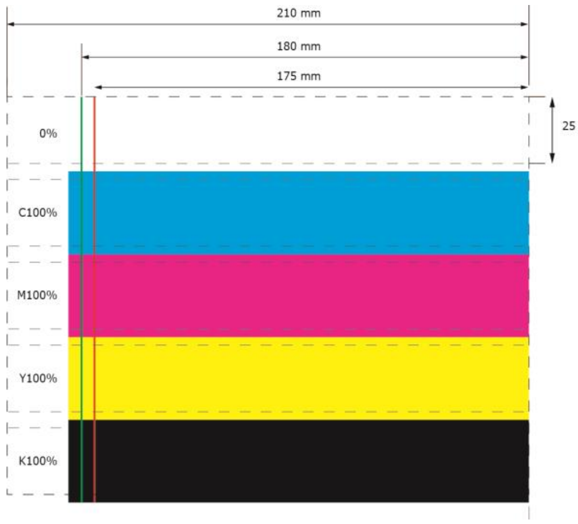


Fig. 1. The dimensions of a single specimen and the design of complete test form.

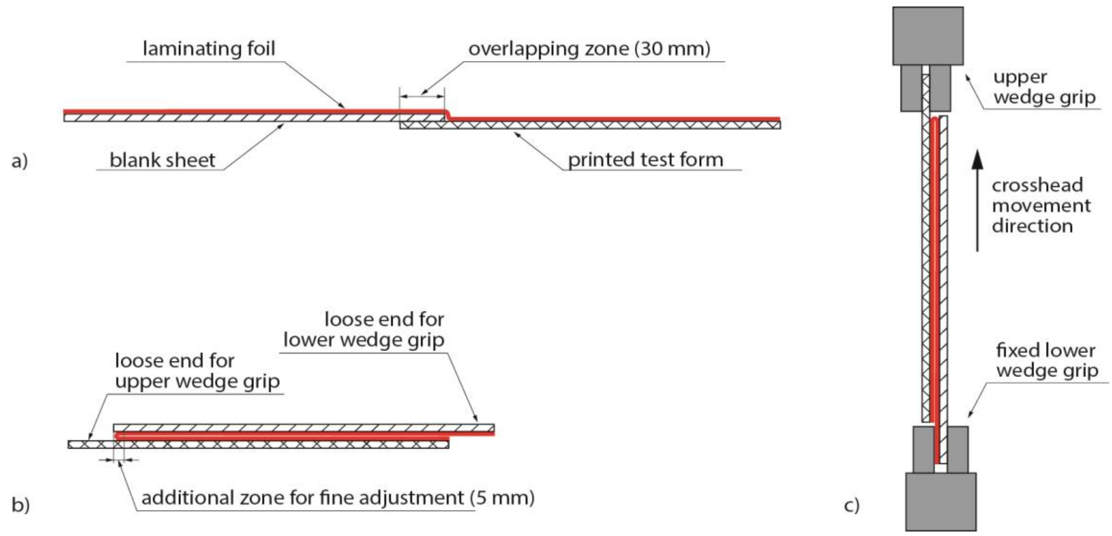


Fig. 2. Schematic overview of the sheet and foil placement (a), the final form of the prepared specimen (b) and its appearance during the peel testing (c)

The 180° peel test was conducted for all prepared laminated samples on a universal testing machine (Shimadzu EZ-LX table top, single column) using high-precision load cell (capacity of 500N, ISO 376 accuracy class 00) and non-shift wedge tensile grips (capacity of 5kN). The speed of traction displacement was constant at 300 mm/min, clamp length 175 mm, sampling frequency of 10 msec, break detection at 50% of maximum load. The testing was controlled and monitored via TRAPEZIUM X software (version 1.4.2, Shimadzu, Japan) in Single mode, peel test. During the peel test all the specimens were first placed into upper grip. After that, the starting line has been finely adjusted by separating manually the laminated foil from the substrate in the zone of additional fine adjustment (see Figure 2b). Afterwards, the specimens were placed into the lower grip. All the specimens had interfacial failure and the surface of the laminating foil looked clean after peeling. None of the specimens had paper failure (paper delamination, fiber tearing off, surface picking, etc.). All measurements were conducted in a controlled environment (at room temperature and standard relative air humidity) and the samples were conditioned for more than 48 hours prior to testing. 20 specimens were prepared for each printing machine, color and laminating foil combination.

Peel resistance is defined as the average force per unit of test specimen width, measured along the bond line that is required to separate progressively two adherend layers of a bonded joint**.** According to the corresponding standards [20-22], the 180° peel strength is determined by using the following equation:

$$\text{Peel strength} = F/w \quad (1)$$

where F is the average peel force (N) and w is the width of the specimen (mm), however, in this paper the [N/25mm] unit was used due to the very low strength values.

Mean values and standard deviations of obtained peel strength values have been calculated for each specimen combination. In order to determine the statistical significance of the differences in the gained peel strength depending on the various sample characteristics (machine type, color and laminating foil), detailed statistical analyses were done by three-way ANOVA with additional two- and one-way ANOVA and the corresponding post hoc tests (Dunnett's T3 post hoc and Welsh and Brown-Forsythe test). Preliminary analyses were performed to ensure no violation of the assumptions of normality, linearity and homogeneity. All the statistical analyses were done using IBM SPSS statistics software (version 20), with an initial significance level of $p < 0.05$. Beside statistical significance, the effect sizes (the practical significance) were also determined for each post hoc test using partial eta squared [23].

RESULTS AND DISCUSSION

The obtained results were analyzed in three stages. First, the derived peel force versus distance curves were examined. In the second stage, the peel strength was analyzed regarding to different printing machines, printing colors and laminating foils, while the third stage was dealing with statistical analysis of differences in the obtained peel strength results. In the following section, results are presented in that manner.

Figure 3 shows a typical example of peel force versus distance curves of one set of investigated parameters (100% of cyan, laminated with matte foil and printed with machine M2). The chart contains 20 individual curves and the average curve, marked with bold red line.

From the presented chart, a couple of remarks can be noticed. First of all, there is no significantly higher peel force at the beginning of the curves. In other word no static strength (peak force to initiate failure) is detected, which suggests that the laminating structure had similar amount of melted resin or copolymer as adhesive over the entire surface of the specimens [24]. Secondly, the noisy, but approximately constant peel curves are referring to the interfacial or adhesive bond failure during peel test. Usually, that kind of bond failure is associated with lower peel rate (24, 25], however in this case, a peel rate of 300 mm/min also resulted in a clean foil delamination from the printed surface. It has to be noted, that although the length of tested specimens was 175 mm, the separation process doubled the overall stroke length, resulting in that excessively long distance or stroke value. Moreover, in some cases a slight foil elongation was noticed during peel test, thus adding more distance in that way to displacement of the measuring head. Furthermore, a comment had to be addressed to the sharp peel force value drop and raising near the end of peel curves, which are correlated to the sheet overlapping during the lamination process. For proper analysis of obtained results, we excluded these extremely high and low peel forces by cropping the peel force-displacement curve from 5 mm to 285 mm (see green bold line in Figure 3).

The obtained mean values of peel strength [N/25 mm] with corresponding standard deviation values for all specimen combination are presented on Figure 4a and b, grouped by laminating foils (gloss and matte), respectively.

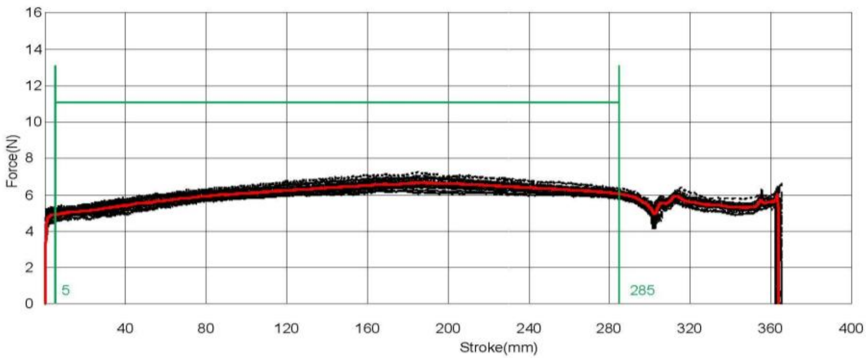
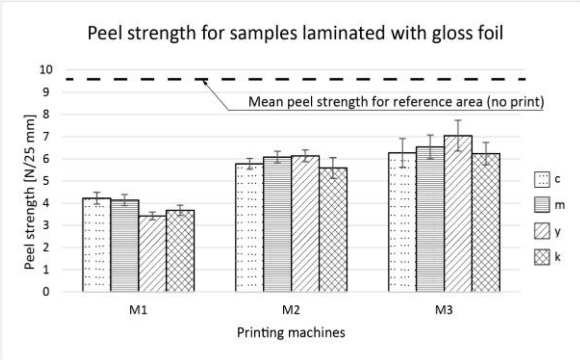


Fig. 3. An example of obtained individual peel curves (dotted black lines) and average peel curve (solid red line) for sample printed with 100% of cyan on machine M2 and laminated with matte foil

a)



b)

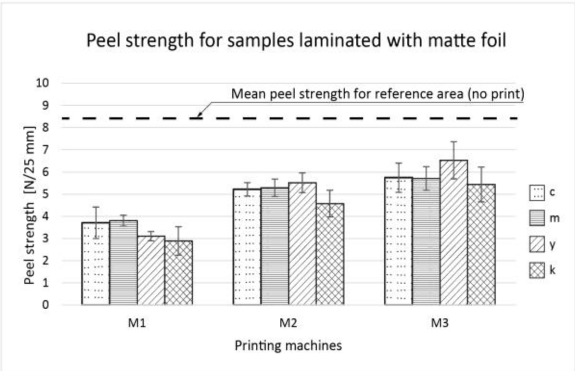


Fig. 4. Mean values of peel strength [N/25mm] with corresponding standard deviation values grouped by gloss (a) and matte laminating foil (b)

As it can be easily noticed from the presented figures, printing machine M1 gained far lower mean peel strength values that the other two printing machines, regardless of the laminating foil. The differences between the mean peel values between machine M2 and M3 were not that significantly expressed for any of the colors, especially cyan and magenta, however there are differences in favor of machine M3, for both laminating foils. By comparing the mean peel strength value of non-printed reference area (9.56 N/25 mm for gloss and 8.43 N/25mm for matte foil), all the observed specimen combinations give visibly lower peel strength values. The lowest mean peel strength value was 65.83% lower, while the highest one was 26.35% lower as well. Since all three printing machines are based on the same principles of electrophotography printing, similar outcomes were expected, which clearly was not the case.

Regarding the process colors, results have varied in relatively narrow range for both laminating foils. For machine M1, mean peel strength values were from 3.42 N/25 cm up to 4.22 N/25 cm for gloss foil and from 2.88 N/25 cm to 3.80 N/25 cm for matte foil. Machine M2 delivered values from 5.58 N/25 cm to 6.13 N/25 cm for gloss foil and from 4.57 N/25 cm to 5.51 N/25 cm for matte foil, while machine M3 had similar range with values of 6.23 N/25 cm ÷ 7.04 N/25 cm for gloss foil and 5.44 N/25 cm ÷ 6.53 N/25cm for matte foil. The low values of standard deviations indicate high consistency of measured values. The corresponding CV values were in most cases less than 10% or slightly above, except two samples for matte foil, printed with M1 machine, where the CV values were around 20%. Furthermore, it can be observed that black color delivered the lowest adhesive bond strength for almost all machines and foil combinations. The exception was the yellow color printed on machine M1 and laminated with gloss foil (3.42 N/25mm). Besides that, the yellow color from the same machine laminated with matte foil derived just slightly higher mean peel value that the black color. Unlike these results, in all other cases, yellow color made the laminate foils adhered the most, especially in the case of machine M3. In addition, it can be also noticed that cyan and magenta delivered very close peel strength values for all printing machines and foil combinations. On the one hand, these typically low values for black ink, and similar values for cyan and magenta, may suggest that the ink composition of applied printing colors could have an influence on the adhesive bond strength in the lamination process. However, on the other hand, the narrow range of obtained results indicates that the applied printing color had less influence on the peel strength than the printing machine or laminating foil.

Comparing the results by the laminating foils, it is showed that gloss foil delivered higher peel strength values for all samples, printed with any color on any machines, without exception. These results could be correlated with the literature findings, according to which gloss foils are more durable and provide a higher level of protection than matte ones [4].

Albeit, the presented graphs can deliver useful information about the differences in peel strength, but they do not set out whether these differences are statistically significant or not. In order to determine the statistical significance of the differences in the gained peel strength values depending on various printing and laminating parameters, statistical analyses were done by three-way ANOVA, with the additional set of two two-way and four one-way between-groups analysis of variance and corresponding post hoc test.

A three-way between-groups analysis of variance (at alpha level of .05) was used to explore the impact of laminating foil (gloss and matte), color (four process colors - cyan, magenta, yellow and black) and printing machine (M1, M2 and M3) on the mean peel strength value.

Statistically significant main effect (p value of .000) was established for all three factors, confirmed by large effect size (above .25). An interaction effect was also statistically significant in case of color and machine, color and foil as well as machine and foil (p value of .000, .000 and .002, respectively). On the other hand, a three-factor interaction effect (machine, foil and color) did perform statistically insignificant result (p value of .078 with small effect size - partial eta squared of 0.024) and observed power of 0.603, which cannot be treated as strong. Thus, significance value being just above the bound of .05 and knowing that the power of a test is very dependent on the size of the sample (individual group size was 20), where insignificant result can be a consequence of small group size, resulted three-factor interaction insignificant effect is recommended to be taken with caution.

When significant result for interaction effect is obtained, follow-up tests are needed in order to explore the relationships more in detail. The first performed test was a two-way between-groups analysis of variance (at alpha level of .05), which was used to explore the impact of laminating foil (gloss and matte) and color (cyan, magenta, yellow and black) on the mean peel strength value for each printing machine (M1, M2 and M3) separately. In case of each printing machine, there was a statistically significant main effect for laminating foil as well as color, with following large effect size: machine M1: laminating foil [$F(1, 152)=66.91$, $p=.000$, partial eta squared=0.31], color [$F(3, 152)=44.95$, $p=.000$, partial eta squared=0.47]; machine M2: laminating foil [$F(1, 152)=324.07$, $p=.000$, partial eta squared=0.68], color [$F(3, 152)=60.33$, $p=.000$, partial eta squared=0.54]; machine M3 laminating foil [$F(1, 152)=86.73$, $p=.000$, partial eta squared=0.36], color [$F(3, 152)=34.48$, $p=.000$, partial eta squared=0.40]. An interaction effect reached statistical significance in case of machines M1[$F(3, 152)=5.36$, $p=.002$, partial eta squared=0.96] and M2 [$F(3, 152)= 16.24$, $p=.000$, partial eta squared=0.24] while in case of machine M3 [$F(3, 152)=0.5$, $p=.68$, partial eta squared=.01] an interaction effect did not perform statistically significant result, but the observed power was extremely low (0.15), thus reached statistical insignificance must be taken with precaution.

According to literature findings [23], when significant result for interaction effect is obtained, which was our case, it is advisable to run follow-up tests to explore this relationship further. Thus, in order to get better insight into each machine and thus color impact on peel strength of laminated material, we have applied broadly used statistical test one-way ANOVA, for each printing machine and each laminating foil. In this analysis we adjusted the alpha level to .10, instead of the traditional .05 level, based on the finding that the power of a test is very dependent on the size of the sample, where the group size of 20 is characterized as small and can lead to wrong conclusion (non-significant result may be due to insufficient power) [23]. As a post hoc tests, we have used Dunnett's T3 post hoc test and Welsh and Brown-Forsythe test.

A one-way between-groups analysis of variance indicated a statistically significant difference at the $p<0.1$ level in mean peel strength of laminated material in case of all three printing machines (for all 4 process colors) and both laminating materials. In the case of gloss foil, the actual difference in mean scores between the groups was large [23]: the effect size, calculated using eta squared, was above 0.14: 0.81, 0.39 and 0.44 for machines M1, M2 and M3, respectively. Post-hoc comparisons using Dunnett's T3 post hoc test indicated that in the case of machine M1, only the mean value of peel strength for cyan process color (M=4.22, SD=0.18) did not differ significantly from mean value for magenta (M=4.13, SD=0.17). In case of machine M2, the mean value of peel strength for cyan process color (M=5.77, SD=0.19) did not differ significantly from mean value for black (M=5.58, SD=0.26) as well as magenta (M=6.07, SD=0.17) and yellow (M=6.13, SD=0.21). For machine M3, the mean value of peel strength for cyan process color (M=6.26, SD=0.47) did not differ significantly from mean value for black (M=6.23, SD=0.36) and magenta (M=6.53, SD=0.28) as well as magenta (M=6.53, SD=0.28) and black (M=6.23, SD=0.36). In all other cases, the mean values differ significantly.

In case of matte foil, the actual difference in mean scores between the groups was also large [23]: the effect size, calculated using eta squared, was above 0.14: 0.40, 0.66 and 0.39 for M1, M2 and M3, respectively. Post-hoc comparisons using Dunnett's T3 post hoc test indicated that in the case of machine M1, only the mean value of peel strength for cyan process color (M=3.70, SD=0.72) did not differ significantly from mean value for magenta (M=3.80, SD=0.25) as well as yellow (M=3.10, SD=0.13) and black (M=2.89, SD=0.65). In case of machine M2, only the mean value of peel strength for cyan process color (M=5.21, SD=0.18) did not differ significantly from mean value for magenta (M=5.28, SD=0.41). For machine M3, the mean value of peel strength for cyan process color (M=5.74, SD=0.49) did not differ significantly from mean value for black (M=5.44, SD=0.65) and magenta (M=5.70, SD=0.68) as well as magenta (M=5.70, SD=0.68) and black (M=5.44, SD=0.65). In all other cases, the mean values differ significantly.

CONCLUSIONS

The lamination process is an excellent surface enhancement technique for print protection against grease, dirt, stains or different type of surface damage, like scratching, rubbing, tearing. Adhesive bond strength or bond strength is one of the main properties of a laminate structure, and its quality assessment is mandatory. This paper is dealing with differences in adhesive bond strength, i.e. peel strength of laminated printed sheets, depending on the used laminating film (gloss and matte), printing color (four process colors, cyan, magenta, yellow and black) and employed digital printing machine. The obtained results showed statistically significant difference at the $p<0.1$ level in mean peel strength of laminated samples in case of all three printing machines (for all four process colors) and both laminating foils. For both laminating foil, gloss and matte, the actual differences in mean peel values between the groups were large (all eta squared values were above 0.14), while according to the performed corresponding post hoc tests (Dunnett's T3), cyan color can stand out as one which does not differ significantly from other color or colors, regardless of printing machines or used foils. Based on the obtained results, it is clear that in order to get more insight into the nature of changes in peel strength values, additional and expanded investigation is needed. This subsequent investigation would include different substrates, papers and paperboards with different surface characteristics, printing techniques, ink compositions, tone values, etc., as influencing factors of printing process, but also different laminating machine set-up parameters.

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REFERENCES

1. H. Chen, B. Jiang, Z-Q. Cai, *Polym. Adv. Technol.*, **26**, 1065 (2014).
2. H. Kipphan, Handbook of Print Media - Technologies and Production Methods, Springer, 2001.
3. https://kaizenprint.co.uk/inspire-support/print-finishing-lamination/
4. https://www.printivity.com/insights/2019/07/09/comparing-matte-vs-gloss-lamination-for-printing/
5. https://www.formaxprinting.com/blog/2011/07/laminated-printing-the-many-benefits-and-uses-of-print-lamination/.
6. https://www.fespa.com/en/news-media/features/the-ultimate-laminating-guide-films-and-applications
7. M. Ataeefard, *Prog. Org. Coat.*, **77**, 1376 (2014).
8. M. Ataeefard, *Pigm. Resin. Technol.*, **44**(4), 232 (2015).
9. Đ. Vujčić, B. Ružičić, *J. Graph. Eng. Des*. **7**(2), 31 (2016).
10. I. Jurič, D. Ranđelović, I. Karlović, I.Tomić, *J. Graph. Eng. Des.* **5**(1), 17 (2014).
11. https://www.astm.org/Standards/ASTM F2296 - 04 (2012)
12. N. Padhye, D. M. Parks, A. H. Slocum, B. L. Trout, *Rev. Sci. Instrum*. **87**, 085111 (2016).
13. http://khushboopackaging.com/products/paper-boards/printing-papers-boards.html
14. https://www.cosmofilms.com/uploads/products/PCT-2%20(DL).pdf
15. https://www.cosmofilms.com/uploads/products/PCT-2%20(M-SIL)%20DL.pdf
16. http://www.adhesivetest.com/resources/docs/FinatTestMethods.pdf
17. https://www.office.xerox.com/latest/D60BR-01.PDF
18. https://www.office.xerox.com/latest/V80BR-01U.pdf
19. https://vipimex.com/files/files/bizhub_PRO_C6000L_General_Brochure.pdf
20. https://www.iso.org/standard/ISO 8510-2:2006
21. https://www.iso.org/standard/ISO 29862:2018
22. S.-H. Lee, S.-W. Yang, E.-S. Park, J.-Y. Hwang, D.-S. Lee, *Coatings*, **9**(1), 61 (2019).
23. J. Pallant, A step by step guide to data analysis using SPSS for Windows (Version 12), Allen & Unwin, 2005.
24. B. Zhao, R. Pelton, *J. Adhes. Sci. Technol*. **17**(6), 815 (2003)
25. B. Zhao, R. Pelton, *Tappi*, **3**(7), 3 (2004).