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MICRO-TOPOGRAPHY ANALYSIS OF FOIL LAMINATED PAPERS

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Abstract:

The surface micro-topography of paper is an important aesthetic feature. It has influence on the paper's printability and also on operation runability and the quality of many post printing processes. Foil lamination as one of the post printing operations has great influence on surface roughness of the substrate. Foil lamination provides the substrates (paper and paperboard) with special visual effects (gloss or matte surface), improves their resistance to various physical and chemical influences and increases the mechanical strength. Besides the adhesive materials and surface adhesion of the used foil, the quality of laminated substrate is mainly governed by the topography characteristics of base paper. The main objective of this study was to investigate the changes in surface roughness of various printing paper after foil lamination process. The surface evaluation have been done by mechanical stylus profilometer (MSP) and for the visual examination of the surface topography the scanning electron microscopy (SEM) micrographs have been analyzed.

Keywords: *laminating foil, paper, surface roughness, MSP, SEM*

1 INTRODUCTION

The surface roughness of paper and paperboard defines the quality and visual appearance of final product. It is an important aesthetic feature and also a functionally important characteristic because it affects the paper's printability and runability in many post printing processes [1, 2]. One of the post printing processes is the foil lamination, which provides paper and paperboard with some special effects, improving their resistance to various physical and chemical influences and mechanical stresses. Since modern, »eye-catching« graphic designs usually require other surface treatment after the lamination process (foil stamping, spot varnishing) the surface roughness of laminated substrates becomes more interesting [3]. In printing and paper industries there are several test methods for measuring the roughness or smoothness of paper including mostly based on air flow measurement. These methods are the standardized surface roughness/smoothness measurement methods [4], but they provide a single parameter (µm by Parker Print Surf method or ml/sec by Bendsten method) which is not sufficient for complete surface analysis [4, 5]. In order to obtain more detailed surface topography evaluation, conventional surface roughness techniques, like the non-contact laser and contact stylus profilometry, or some imaging techniques, such as scanning electron microscopy or atomic force microscopy, can be applied [6-8].

2 MATERIALS AND METHODS

Three types of commercial paper have been chosen for this study: Sample 1- uncoated, with basic weight of 140 g/m², Sample 2 - gloss- and Sample 3 - matte-coated papers with basic weights of 150 g/m². The selected papers have been laminated on Aspira 76 hot foil laminating machine with three standard gloss foils: 24 µm thick BOPP roll laminating foil, 75 µm and 125 µm thick OPP laminating foils. The working parameters of the laminating machine were: temperature 115 °C, speed 8m/min, pressing force 22 kN. Each sample was measured three times in machine and cross direction on five randomly marked patches, altogether 30 measurements for each sample. With this approach the influence of the direction of paper formation on the measured values could be avoided and the accuracy of the measurements could be ensured.

As a mechanical stylus profilometer, the TR 200 Portable Surface Roughness Tester with a diamond stylus tip of 2 µm radius has been used. The instrument is compatible with ISO 4287, DIN 4768, ANSI B 46.1 and JIS B601 standards and it can be used for measuring 13 different roughness parameters (R_a, R_z, R_y, R_q, R_t, R_p, R_{max}, R_m, R_{3z}, S, S_m, S_k, tp) with four filtering methods (RC, PC-RC, Gauss, DP). Five evaluation length (1~5*sampling length) and four measuring ranges (auto, ±20 µm, ±40 µm, ±80 µm) with the corresponding resolution can be chosen (0.01 µm ~0.04 µm). The sampling lengths (auto, 0.25 mm, 0.8 mm, 2.5 mm) have to be select according to range values of Ra (average surface roughness) and Rz (mean value of single roughness depths) of the observed surface. The recommended instrument's set up values are presented in Table 1 [9].

Table 1. Selected sampling length with the corresponding traversing speed

R_a [µm]	**R_z [µm]**	**Sampling length [mm]**	**Evaluating length [mm]**
… 0.1	… 0.5	0.25	1.25
0.1 … 2	0.5 … 10	0.8	4
2 … 10	10 … 50	2.5	12.5
10 …	50 …	8	10

For the surface roughness analysis the following parameters have been chosen [9-11]:
R_a - average surface roughness, which is defined as the average absolute deviation of the roughness irregularities from the mean line over one sampling length.

$$Ra = \frac{1}{L}\int_0^L |y(x)|dx \qquad (1)$$

R_q or R_{ms} - root mean square roughness represents the standard deviation of the distribution of surface heights. It can be calculated as the square root of the arithmetic mean of the squares of profile deviation from the mean line within the sampling length.

$$R_q = \sqrt{\frac{1}{L}\int_0^L \{y(x)\}^2 dx} \qquad (2)$$

R_{zDIN} – is mean value of single roughness depths for contact measurements.

$$R_{z(DIN)} = \frac{1}{n}(Z_1 + Z_2 + ... + Z_n) \qquad (3)$$

R_p - leveling depth is defined as the maximum height of the profile above the mean line within the evaluation length.

The measuring range of 20 μm with corresponding resolution of 0.01 μm, evaluation or assessment length of 5 sampling lengths and the Gauss filtering method have been used for measuring all samples. The sampling lengths with the corresponding traversing speed have been chosen according to [9-11] and they are presented in the Table 2.

Table 2. Selected sampling length with the corresponding traversing speed

Type of samples	Sampling length [mm]	Traversing speed [mm/s]	Evaluation length [mm]
Uncoated paper without foil	2.5	1	12.5
Matt coated paper without foil Gloss coated paper without foil Uncoated paper with 24 μm foil Matt coated paper with 24 μm foil Gloss coated paper with 24 μm foil	0.8	0.5	4
24 μm foil 75 μm foil 125 μm foil Uncoated paper with 75 μm foil Uncoated paper with 125 μm foil Matt coated paper with 75 μm foil Matt coated paper with 125 μm foil Gloss coated paper with 75 μm foil Gloss coated paper with 125 μm foil	0.25	0.135	1.25

The SEM micrographs of the samples were made by JEOL JSM 6460 LV scanning electron microscope. In order to get required electrical properties, the samples have been gold coated by ion sputtering (15.0 nm thick, density 19.32 g/cm^3). The images were taken at working distance of 15 mm and angle 30° at voltage 20 kV with magnification of 200x and 10.000x.

3 RESULTS AND DISCUSSION

3.1 Measurement of the roughness parameters

The mean values of measured roughness parameters (R_a, R_q, R_{zDIN} and R_p) for uncoated, matte coated and gloss coated papers and their laminated combinations with foils are presented in Table 3, 4 and 5, respectively.

Table 3. The mean values of measured roughness parameters for uncoated papers

Roughness parameters	Uncoated paper			
	Without foil	+ 24 μm foil	+ 75 μm foil	+ 125 μm foil
R_a [μm]	3.084	0.704	0.033	0.027
R_q [μm]	3.844	0.835	0.049	0.041
R_{zDIN} [μm]	20.694	2.856	0.287	0.247
R_p [μm]	8.109	1.440	0.202	0.176

Table 4. The mean values of measured roughness parameters for matte coated papers

Roughness parameters	Matte coated paper			
	Without foil	+ 24 µm foil	+ 75 µm foil	+ 125 µm foil
R_a [µm]	0.657	0.267	0.026	0.021
R_q [µm]	0.836	0.325	0.039	0.032
R_{zDIN} [µm]	4.250	1.195	0.222	0.215
R_p [µm]	1.828	0.618	0.167	0.146

Table 5. The mean values of measured roughness parameters for gloss coated papers

Roughness parameters	Gloss coated paper			
	Without foil	+ 24 µm foil	+ 75 µm foil	+ 125 µm foil
R_a [µm]	0.396	0.212	0.031	0.021
R_q [µm]	0.514	0.256	0.047	0.033
R_{zDIN} [µm]	2.635	0.929	0.266	0.195
R_p [µm]	1.047	0.483	0.199	0.145

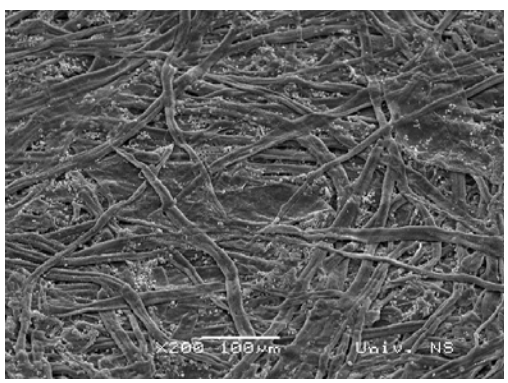
In general, all surface roughness parameters have similar tendency of decreasing as the thickness of laminating foil increase, which can be clearly seen from Table 3, 4 and 5. The uncoated paper (without foil lamination) has the highest values for all roughness parameters, corresponding to stochastic nature of paper surface without any surface processing techniques. Coated papers, as can be seen in Table 4 and 5, have significantly lower values for all measured parameters in comparison to uncoated paper's parameters. The most rapid decay of values for all roughness parameters was registered for the uncoated paper + 24 µm foil laminate structure, which means that most of the high peaks and deep walleyes on the base paper's surface have been straightened by foil lamination (heat-treatment and pressure). With thicker foils this straightening is more intensive, since there is more material (foil and adhesives) to fill the walleyes and leveling the peaks. Analyzing the changes in surface roughness of the foils before and after lamination processes, it can be noticed that foils with different thickness behave different. The R_a parameter of the 24 µm thick, raw foil has been increased in the laminating process: instead of 0.077 µm, it becomes 0.704, 0.267 and 0.212 µm for the uncoated, matte and gloss coated paper, respectively (see Table 3, 4, 5 and 6). In comparison with obtained results of 75 and 125 µm thick foils and laminated structures, it can be observed that there are no significant changes in surface roughness of raw foils and all combinations of laminated structures, since the measured values of Ra and Rq for all paper-foil combinations are close to each other (see Table 3, 4, 5 and 6).

Table 6. The mean values of measured roughness parameters for laminating foils

Roughness parameters	Laminating foil		
	24 µm	75 µm	125 µm
R_a [µm]	0.072	0.031	0.022
R_q [µm]	0.088	0.047	0.033
R_{zDIN} [µm]	0.355	0.259	0.187
R_p [µm]	0.187	0.189	0.140

3.2 SEM analysis

Typical SEM micrographs of uncoated, matte and gloss coated paper have been presented on Figure 1a, 2a and 3a, respectively. It can be clearly seen that the coating process makes the paper's naturally rough and stochastic surface relatively smooth. That relatively even surface has no visible influence on the waviness parameter of the laminated structures. Observing the micrographs on Figure 1b, 2b and 3b, which present the laminated structures, the above mentioned papers laminated with 24 µm thick foil, it can be noticed that only uncoated paper's waviness reflected significantly on the laminated structure. The SEM micrograph on Figure 1b has slightly cloudy structure, while the foil after lamination on the uncoated paper became wavy. For other paper - foil combinations this type of change in topography is not noticeable. From the obtained micrographs for every laminated surfaces it could be discernible the randomly distributed knobs. The presented SEM micrographs confirm the results of surface roughness parameters obtained by profilometric measurement. The visually most rough surface corresponds to the highest Ra parameter values measured (uncoated paper, Table 3, Figure 1a). Comparing the micrographs of three laminated substrates it is also obvious that the uncoated laminated structure has more rough surface than the coated laminated structures, which are very similar (see Figure 1b, 2b and 3b). This visual observation also approves the measured values for these samples (see Table 3, 4 and 5).

a) 

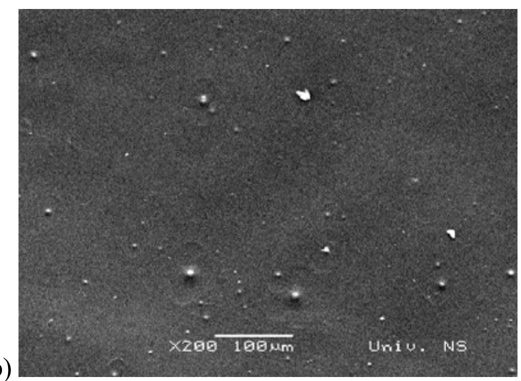
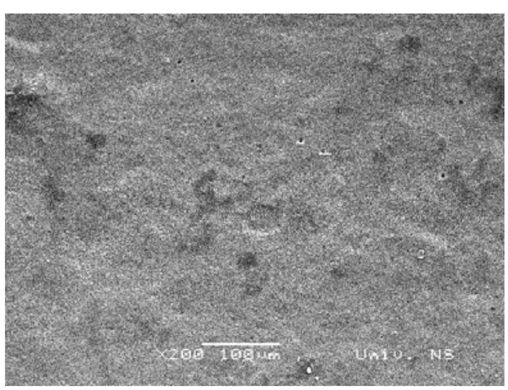
b) 

Figure 1. SEM micrograph of uncoated paper without foil (a) and laminated with 24 µm foil (b)

a) 

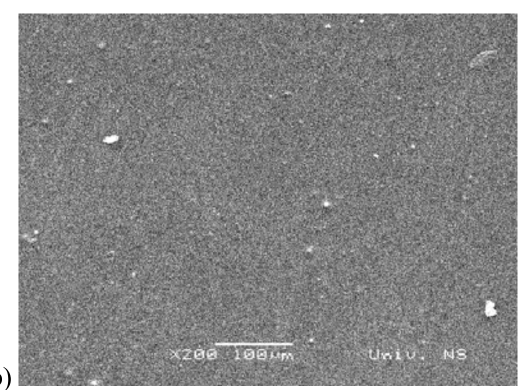
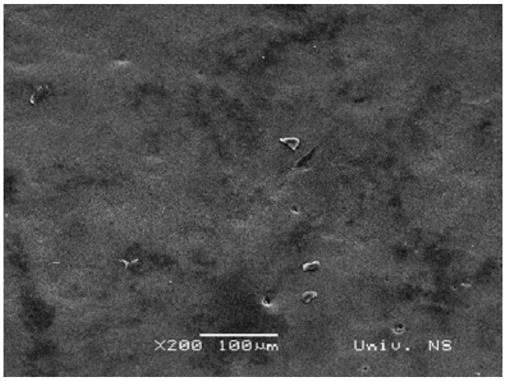
b) 

Figure 2. SEM micrograph of matte coated paper without foil (a) and laminated with 24 µm foil (b)

a) 

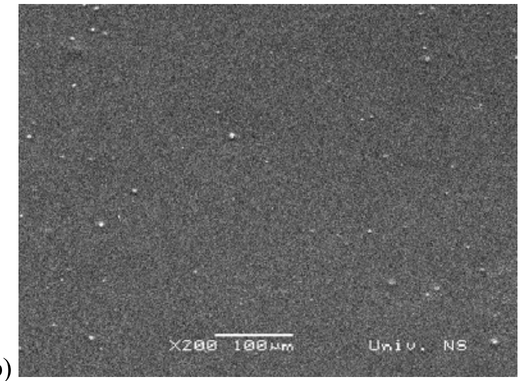
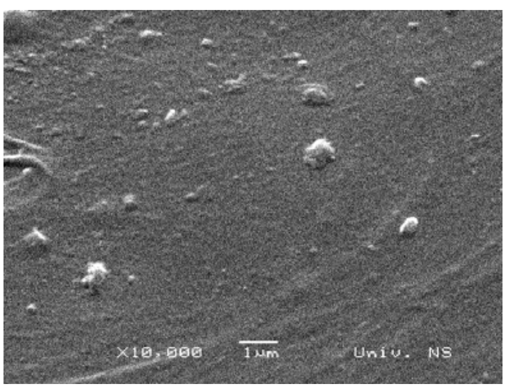
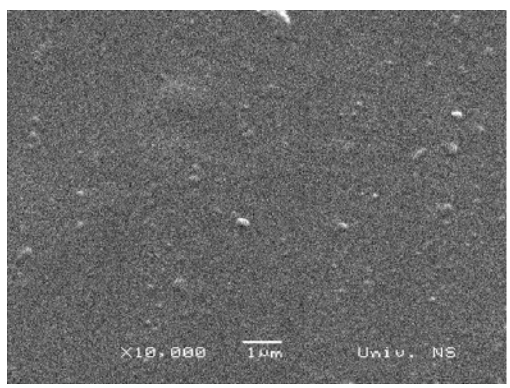
b) 

Figure 3. SEM micrograph of gloss coated paper without foil (a) and laminated with 24 µm foil (b)

Representative SEM micrographs of raw laminating foils with thickness of 24 µm, 75 µm and 125 µm are presented on Figure 4a, 4b and 4c respectively, taken with magnification of 10.000x. On the observed surfaces of raw foils micro relieves can be noticed. These micro relieves are more emphasized on 24 µm thick foil than the 75 µm thick foil and on 125 µm thick foil they are not visible at magnification of 10.000x (Figure 4c). The 24 µm thick film seemed to have more slopes and peaks distributed randomly besides the mentioned micro relives than 75 µm foil. Comparing the micrographs of three raw foils there is noticeable that the 24 µm foil has uneven, more rough surface than the thicker foils, which complies with the results for surface roughness parameters (R_a, R_q, R_{zDIN} and R_p) obtained by profilometric measurement (Table 6).

a) 

b) 

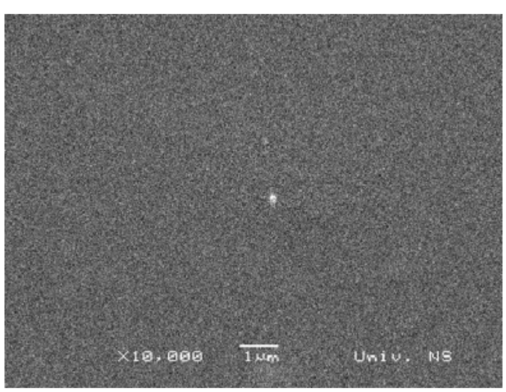
c) 

Figure 4. Typical SEM micrograph of surfaces of 24 µm (a),75 µm (b) and 125 µm thick raw foils

4 CONCLUSION

Surface micro-topography of laminated paper structures became an important feature in graphic industry, since demands for attractive printed products are rising every day. For better understanding of the laminating process and its visual effects on printed products a detailed surface investigation is needed. In this study a profilometric and optical method has been used to quantify and qualify the surface characteristics of three different commercial papers and laminated combinations of those papers with three different foils. The objective surface evaluation has been done by mechanical stylus profilometer and for the visual examination of the surface topography the scanning electron microscopy micrographs have been analyzed. The obtained results from profilometric measurement show that all observed surface roughness parameters have similar tendency of decreasing as the thickness of laminating foil increased. The results indicate that the waviness of the base paper could have significant visual affect on the laminated surface structures, mostly for thin foils (<24 µm). The visual examination of surface micro-topography on the SEM micrographs approved the obtained results of roughness parameters and gave a detailed insight of raw foil surface characteristics. For further investigation a broader range of foils and laminating conditions have to be observed, since the materials and laminating conditions described in this paper cover just a small segment of industrial applications.

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