Topographical micro-changes on corrugated board liners – A comparison between laboratory and full-scale effects.

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Abstract

Printing on corrugated board is a complex process; many input variables affect the results to a varying extent. Not only the printing process itself has an influence on print quality; the pre-conditions of the substrate affect it as well. The topography of the liner surface is one of many important influence factors. As a first step, laboratory tests concerning the influence of the corrugated board production process on the liner surface topography were carried out (Rehberger et al., 2006). The result was that the movement of the liner on a hot plate, as compared to unmoved sheets, is the major criteria in surface roughness changes on coated and uncoated liners. Pilot trials have been carried out, since laboratory tests cannot be scaled up to real conditions. The first pilot trial with an uncoated liner did not result in any surface topography changes in conjunction with gloss, even though the corrugator was set to extreme temperature, pressure and speed conditions. These settings were adjusted to the pre-heater and double facer of the corrugator. The second pilot trial with coated liners, though, showed a clear impact on the topography of the liner surface. Using STFI-MicroGloss meter, the visually perceivable gloss lines have been analyzed and, as result, the average gloss line values computed. The results showed that production speed has the highest influence. The topographical measurements with AFM, FRT-MicroProf® and CLSM disclosed that these glossy stripes have a much lower nano-scale surface roughness as compared to the raw material. An extreme condition occurs when the corrugator is restarted after a full-stop. One collected sample from the start-up showed longish bubbles across the flute. Not only low-speed causes gloss lines, so do also the standard settings set by the operator for optimum corrugated board quality.

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Finally, printing trials in flexography and ink-jet were performed to determine the gloss influence of the substrate and whether the gloss lines still appear in the print. The print images were measured with the STFI-MicroGloss. The result for the flexographic printed images is that none of the gloss lines from the substrate appears in the print. The same is valid for the ink-jet printed images. Only the gloss from the print is recognizable. Further trials are necessary to shed light on the interrelation between substrate, gloss and print quality.

Introduction

The technical goal in printing is to achieve good image quality, matching the original as closely as possible, or to print fonts without distortion. Regarding packaging print, and especially print on corrugated board, everyone's aim, from the paper maker to the printer, is to achieve this goal while fulfilling the mechanical requirements of the packaging as well. Good print quality is however dependent on many factors and the paper plays a substantial role

It is generally accepted that the printability properties of paper are dependent on the uniformity of the paper structure on the micro- and nano-scale. Such properties are surface roughness, paper gloss, opacity and absorbency (Järnström et al., 2006; Zang et al, 1995). Paper gloss quality is related to the average reflectivity in the specular direction, but also the distribution of gloss structure and patterns on the paper. Further processing of the paper as well is influencing its properties, e.g. producing corrugated board (Pinnington 2003, Mensing 2003). Paper-metal friction is mainly occurring in a corrugator. Friction on paper causes changes in surface roughness and can lead to gloss effects if a certain roughness value is exceeded. Gloss is a factor mainly dependent on the macro and micro topography of the sheets (Zhang et al., 2001, Santos et al., 2004)). In the present article the correlation between variations in the surface roughness and gloss will be enlightened.

The process of ink setting requires various physical and chemical paper-ink interaction properties to fulfill the demands for good print quality (Rentzhog, 2004; Vikman 2004). Papers for higher print quality demands are commonly coated. Different mechanisms influence the print result in this case. The coating layer keeps the ink particles on the top surface, whereas with uncoated papers the particles are more unevenly absorbed and dispersed in the top layers. This is an important difference concerning the optical properties of printed sheets.

Materials

The full scale trials and the combination of paper qualities were dependent in accordance to the production demands of the corrugated board factory. Therefore, the selection was contingent on the outer liner, i.e. the printing side of the sheet. For the pilot trials, the following paper qualities were chosen:

Pilot Trial 1

- Outer liner: Kraftliner whiteTop 135g/m^2 (white liner)
- Fluting: Wellenstoff 170g/m^2, B-Flute
- Inner liner: Testliner brown 160g/m^2

Pilot Trial 2

- Outer liner: WhiteLiner double coated 140g/m^2
- Fluting: Wellenstoff 110g/m^2, E-Flute
- Inner liner: Testliner White 140g/m^2

The samples were taken from the middle of the production width and all settings and data about the corrugator during the test run have been recorded. During the test run, the first pre-setting was the standard setting, which is the optimal configuration for the chosen quality. Tables 1 and 2 illustrate the test run pre-settings for the operator of the corrugator. Column 1 presents the standard configuration and the rest of the columns the variations.

Table 1 Pre-settings for Pilot Trial 1

Trial 1			**1**	**2**	**3**	**4**	**5**
Pre-Heater	**temp**	**°C**	L				H
Double Facer	**temp**	**°C**	M	H			
Double Facer	**pressure**	**steps (0-3)**	3	max. already reached			
Corrugator	**speed**	**m/min**	200		300	50	

Table 2 Pre-settings for Pilot Trial 2

Trial 2			**1**	**2**	**3**	**4**
Pre-Heater	**temp**	**°C**	L	H		
Double Facer	**temp**	**°C**	L		H	
Double Facer	**pressure**	**steps (0-3)**	3	max. already reached		
Corrugator	**speed**	**m/min**	150			50

L – low values, M – middle values, H – high values, DF pressure (low) 0, 1, 2, 3 (high)

Concerning the comparison between laboratory scale and full scale, the laboratory trials are described in-depth in a previously released paper, Rehberger et al., 2006. The tests reported in that paper were focused on uncoated papers. In the present publication, the data for the coated liners is included. The laboratory test (Figure 1) is set up in order to comply with the corrugator procedures. These tests only contain the process steps from the reel stand of the liner to the end of the double facer. The paper is pre-heated in the laboratory with a heating plate on the gluing side. After turning the sheet, it is loaded with a tool, which has a flute profile milled into. This tool simulates the flute profile and the load from the double facer top heating plates. During that last step, one set of liners (10sM) is moved back and forth on the laboratory heating plate. For the other set (10s), this movement step is skipped to measure the difference of moved and unmoved paper on a hot plate. This procedure is applied to coated and uncoated qualities and the following qualities are chosen to be compared with the full scale test:

Laboratory Trial

- Uncoated liner: Kraftliner 175g/m^2 (white top) (Code: 2u175)
- Coated liner: Kraftliner double coated 130g/m^2 (Code: 2dc130); this quality is added in the laboratory trial

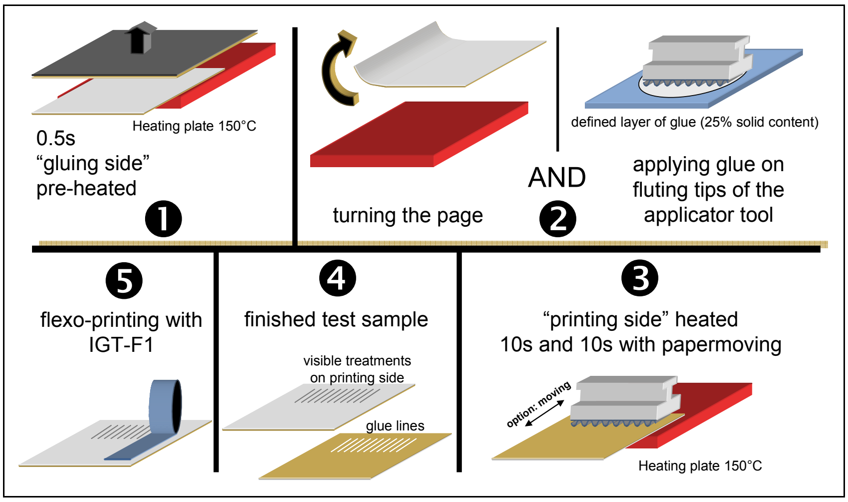

Figure 1 Test procedure for producing differently treated samples. Step (1) is to pre-heat the liner for curing the applied glue. Number (2): the liner sheet is turned and glue is applied on the applicator made of Teflon®. Step (3) simulates the Double Baker process, where the fluting and liner are glued together. In this case, only glue stripes are applied. The finished samples (4) now have cured glue lines at the inner side and quite visible surface changes on the printing side, depending on the treatment (step 3). The last step (5) was printing on the samples with the IGT F1 Flexo laboratory printing machine.

Methods

Gloss measurements

The MicroGloss meter by STFI-Packforsk captures gloss images from the sample by using a 20°/20° setup for camera and illumination. A series of single images with a size of 13x13 mm are captured and afterwards merged together to a 3x3 image matrix. The merged images are processed with Matlab® calculating the average grey level representing the local gloss along lines. This calculation is performed in both the horizontal and the vertical direction (see Figure 2).

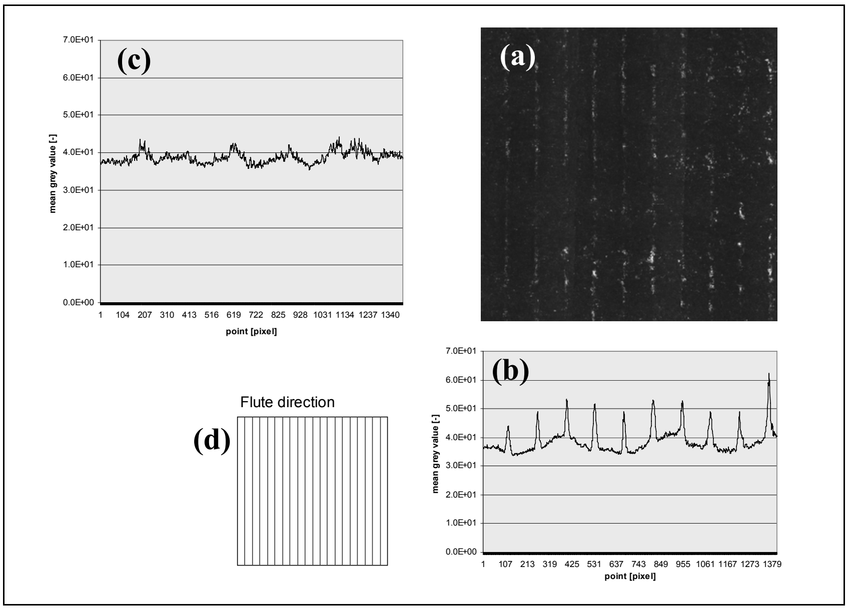

Figure 2 Demonstration how the horizontally and vertically oriented average grey level, representing the gloss, is captured. (a) captured image, (b) average grey value in flute direction, (c) average grey value in cross direction and (d) indication of flute direction.

Topographical measurements

FRT MicroProf® is used to investigate the topography of a scanned surface. It is a non-contact method and surface height profiles indicating roughness and waviness can be acquired. Its principle is based on chromatic aberration where white light is split up into different colors focused on different heights. The light reflected by the surface is analyzed and the data is computed into a topographical image. The measurements with FRT-MicroProf® have been performed at a resolution of 1000x1000 pixels in a range of 1x1 mm leading to a resolution of 1 µm in the x-y-direction. The z-direction resolution is better than 10 nm.

CLSM (Confocal Laser Scanning Microscopy) is a tool used to produce section images of thick specimens at various depths or to get topography maps. The Radiance 2000 (Bio-Rad Laboratories, USA), which is used for measuring the surface of the samples, uses a Kr/Ar laser. The images from each layer are afterwards computed to a 3-dimensional topographical image. CLSM was used in the laboratory tests to determine the surface topography, but not for the pilot trials (see "Results and Discussion"). The chosen magnification is 20 x and the image size is 0.6 mm.

AFM (Atomic Force Microscopy) NanoScope IIIa Multimode from Digital Instruments is a tool capable of scanning surfaces on the atomic level. It captures images of a maximum size of 100x100 µm and a z-direction working range of 6 µm. A measurement head oscillates over the surface and measures the normal and lateral deflection. This gives information about the topography and material properties, such as elasticity. Two types of images were taken, one of larger sizes between 10x10 µm and 30x30 µm to illustrate the surface topography. The second type was taken to analyze the surface roughness on the nano-scale. This, however, was performed only on the coated qualities from the pilot trial 2. The samples from the laboratory trial already have been successfully examined with the CLSM technique.

Printing

Flexo post-print is the most common printing method for corrugated board printing. It is used for simple one-color print as well as for multi-color print. Above a certain lot-size, flexo-post-print is cheaper than offset-pre-print, but the flexibility is still missing. Digital print is the key-technology for variable printing and there are intensive attempts to make this technique competitive. Digital printing is in this case ink-jet printing. The great advantage is that the print can be changed instantly and every sheet printed differently if needed. For the tests, it was important to see if a conventional printing method with direct contact with the substrate shows any difference to a non-impact printing (NIP) method such as ink-jet.

In the pilot trial, the Flexo-Print is performed with the IGT-F1 Flexo Tester, the same method as in the laboratory tests. This printing machine is built for laboratory use with printing speeds between 0.2 and 1.5 m/s and a printing width of 50 mm. The cliché diameter on the cylinder must be 170 ±1 mm and enables one-color printing. For the laboratory tests, a DuPont DPC digital cliché with a thickness of 1.7 mm and a hardness of 40 Shore A was used. This cliché is flexible in its properties and therefore it is possible to use it again for the new samples, the coated liners on E-flute corrugated board. The anilox roll has a cell volume of 2.7 ml/m², a screen angle of 60° and a resolution of 235 l/cm (IGT-Ref.no.: 402.419). The printing cliché is mounted with DuploFLEX 5.3 (Lohmann Klebebandsysteme, Neuwied, Germany) with a thickness of 0.55 mm and compressible properties. The used flexo-ink is a water-based cyan ink, Scanbrite 4-Color Blue Raster (ID: 707-44836) from SunChemical. It is diluted with demineralized water and adjusted to 21 s with DIN Cup #4.

The digital print was performed at HP Scitex (Zaventem, Belgium) with the HP Scitex FB6700. The printing head from Aprion® is able to accelerate 25,000 droplets/sec/nozzle, has a resolution of true 600dpi and works in FM mode (stochastic). It prints with HP Scitex WB300 Supreme ink, which is a pigmented water-based ink, and the machine can be filled with the colors C, M, Y, K, LC and LM. For the test only Cyan was used.

Results and Discussion

Gloss stripes on corrugated board can be easily detected when the sheets are held at a 45 degree angle in reflecting light from a light source. It is thus possible to some degree to predict directly after the corrugator the results of the gloss and topographical measurements. The uncoated liners on B-flute from the pilot trial 1 did not, however, show any gloss effect. As illustrated in Table 1, the settings for the corrugator were extreme in all cases: highest temperature, pressure and lowest speed. In the second pilot trial, performed with coated qualities on E-flute, it was instantly recognizable that the sheets had glossy lines all over. The following chapters will explain these results.

Evaluation of Raw Materials

Light Microscopy

In order to evaluate the occurrence of gloss on coated outer liners of corrugated board, images were taken with bright-field reflected light microscopy. Polarized light highlighted the polished surface parts best. Figure 4 (a) and (b) illustrates a spot on a flute tip at different magnification. Images (c) and (d) are prepared to emphasize the gloss areas.

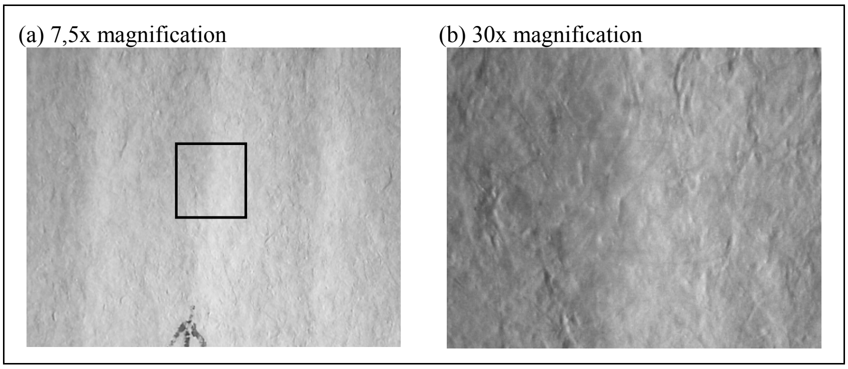

Figure 3 Light Microscopy images with an illumination angle of 5° from the paper surface plane. In image (a) the fiber structure can be observed, visible through the coating. Image (b) (black square, image (a)) illustrates a glossy area in the centre, which is clearly detectable. The tip line is aligned vertically.

The difference between the tip and valley is clearly visible, but the polished area is not uniform. The structure of the polished area seems to be dependent on the fiber structure of the base paper. The fiber layer beneath the coating is detectable in the polished structure. The images in Figure 3 are illuminated with trailing light at a 5 degree angle from the paper plane and across the flute direction. The images (a) and (b) in Figure 3 show the effect of uneven polished areas. The fiber structure beneath the coating is recognizable. In the centre of image (b), the glossy spot with its smoother surface is detectable, but still the fiber structure in the coating is present.

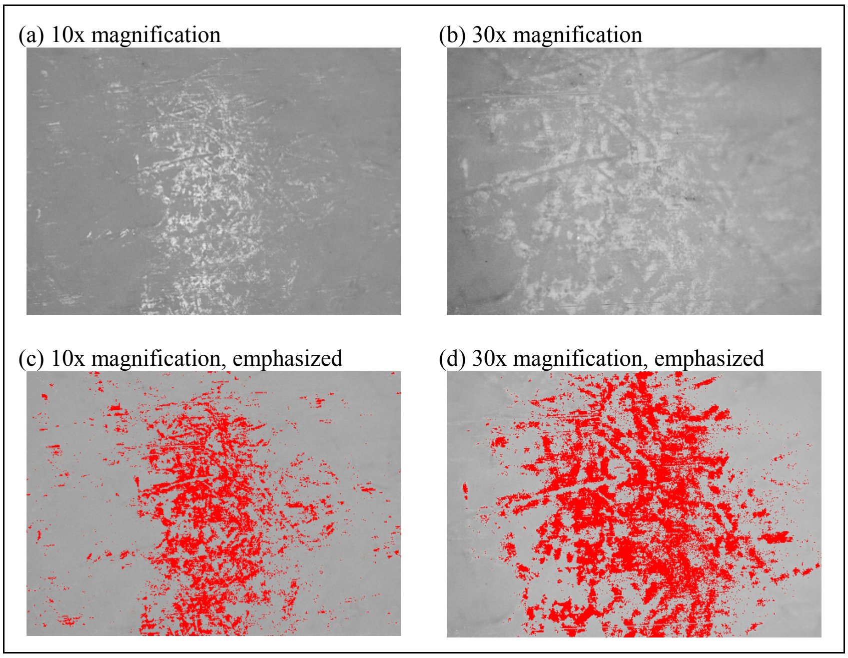

Figure 4 Light Microscopy images from glossy spots on the samples. Images (a) and (c) at a 10x magnification and images (b) and (d) at 20x. All are captured with polarized light.

Gloss measurements

The measurements with STFI MicroGloss meter should determine whether gloss lines occur on the surface of the samples. All samples from the laboratory tests showed gloss lines on the surface in the same pattern they had been loaded from the lab tool, described in the "Materials" chapter.

The polished areas on the coated liners are more distinct on the flute tips, than in the valleys. However, with the uncoated liners, gloss lines are only visible on the flute tips and not even every tip line is affected. The set-up of the laboratory tests is simulating the corrugator process steps, but speed and time are critical factors. Compared to real conditions the laboratory settings have been more drastic in their consequences and therefore the results showed increased values to a much higher extent. Subsequently, the changes in the surface structure of uncoated liners, which could be detected at a laboratory scale, might not take place in regularly produced corrugated board. The aim was not to get absolute values but a relative trend of what might be the most critical factor affecting gloss stripes.

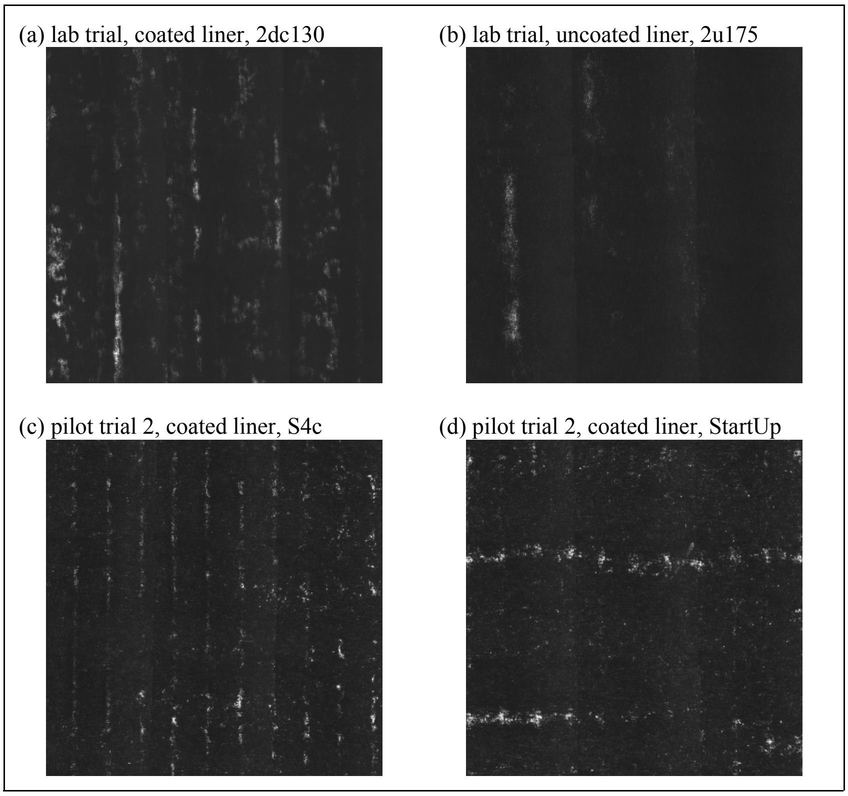

Figure 5 Images captured with STFI MicroGloss meter. (a) and (b) are unprinted samples prepared in the lab. (c) and (d) are samples from the pilot trial 2.

The second stage in the project was the pilot trials and, as mentioned before, gloss lines on the uncoated liners in pilot trial 1 are visually not observable. This is confirmed by the STFI MicroGloss measurements; none of the samples show any gloss effects in the form of stripes. The coated samples from the pilot trial 2, on the other hand, showed rather large gloss line effects. The measurements proved the visual observation right, which is illustrated in Figure 5 (c). Image (d) is an exception, because this sample was collected at the start-up of the production order. The corrugator was at its lowest speed, approx 10 m/min, and longish bubbles in the machine direction, i.e. across the flute direction, are visible.

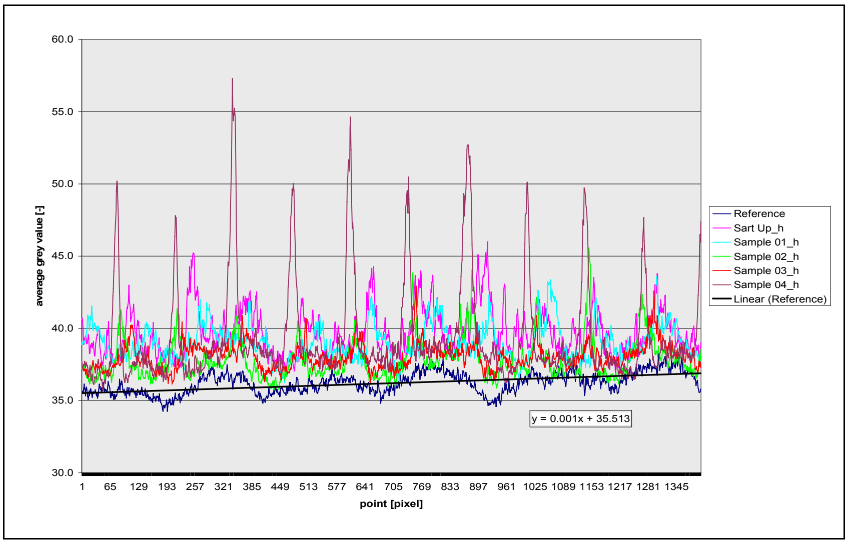

Figure 6 Vertically averaged grey values of scanned images from the coated samples. The average grey value represents the average gloss value in the flute direction (image size 1400x1400 pixels).

The gloss images of the other samples are not included in this paper, but the result for the average gloss is included in Figure 6. As can be seen, the highest peaks are generated by sample 04_h (h= horizontal scan), followed closely by the start-up sample. All other samples have less but still visible gloss effects. Therefore, it was decided to choose sample 4 coated (S4c) for further tests.

Topographical Measurements

For the topographical evaluation of the laboratory test, the uncoated liners have been examined with CLSM. Problems occurred when measuring the coated samples from the pilot trial 2 with CLSM on the glossy spots. The results did not correlate with all other results, e.g. from AFM and FRT-MicroProf®. Compared to the reference, the glossy spots had a higher surface roughness. It was assumed that mirroring effects on the glossy surface influence the result. As described in the previous chapter, sample 4 coated (S4c), collected from the pilot trial 2 with coated liners, was chosen for topography studies with AFM and FRT-MicroProf®.

CLSM measurements with laboratory samples

Sample 2u175 from the laboratory test was investigated primary with CLSM in order to gather surface roughness values. Figure 7 illustrates the decrease in Rq from sample "10sM" on the tip of the flute. In addition, moving and heating of the liner, represented by sample "10s", has no influence on surface roughness.

This result, even if not directly transferable to mill conditions, gives an indication to the effects at the mill scale.

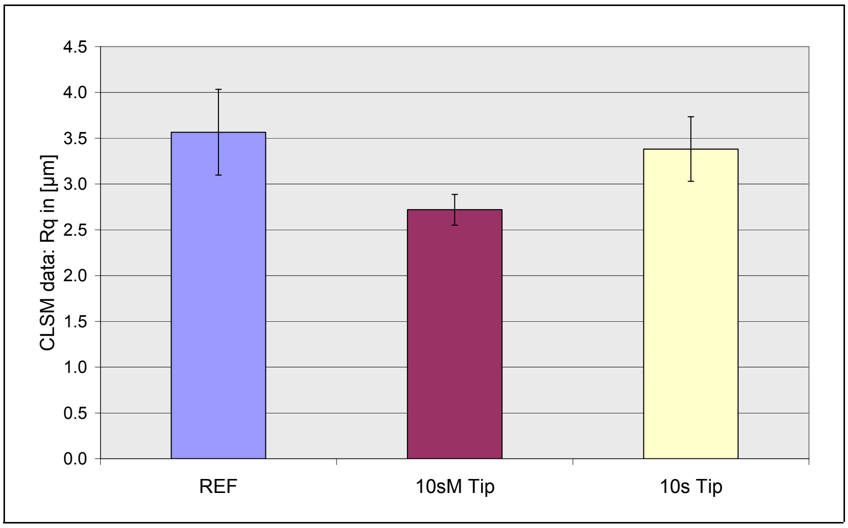

Figure 7 CLSM analysis with uncoated samples 2u175 from the laboratory trial. The surface roughness of 10sM is, compared to the reference, reduced through movement on the hot plate. The unmoved liner (10s) shows no change at all.

FRT MicroProf®

The measurements, described in the chapter "Methods", with the sample S4c are set up to measure at the highest possible resolution of this instrument. Some pre-studies with 5 µm/pixel showed, that a too low resolution leads to incorrect results, because the MicroProf® measures in the micro-scale. The surface roughness on coated papers appears on the nano-scale and even the maximum resolution of 1 µm/pixel might be too low for exact values, but enough for a good trend. The measurement area is important as well. In Figure 8, the scan areas of 0.5x0.5 mm and 0.25x0.25 mm are illustrated, but these areas are zoomed out from the original image with a size of 1 mm. The reason for this was described above in the subchapter "Light Microscopy". The structure from the fibers beneath the coating is still visible and the polished zone on the fibers has to be marked and extracted. The trend of the chart is the same for both zoom values, the nano-scale surface roughness is strongly reduced in the gloss areas. The only difference is that the standard deviation for the 0.25 mm scan area is narrower than that of the 0.5mm area. More accurate results have to be procured with the AFM.

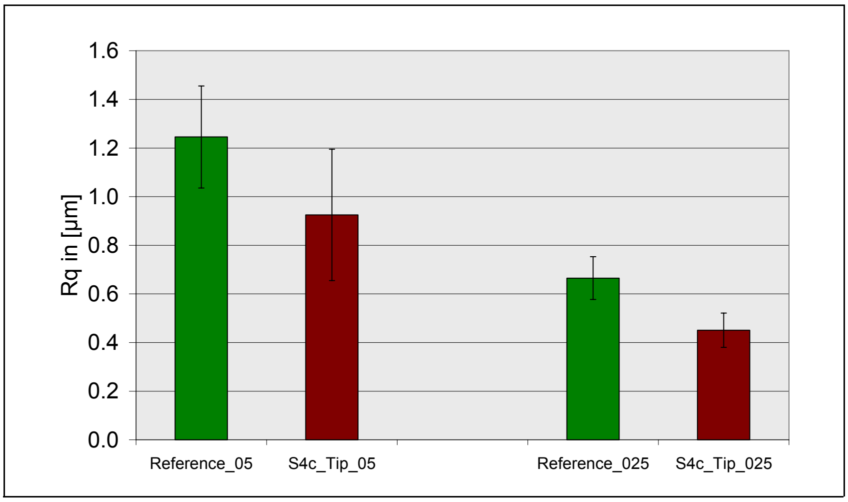

Figure 8 The results for the topographical measurements with FRT-MicroProf®. Left bars marked with "05" have an image size of 0.5x0.5 mm and the right bars an image size of 0.25x0.25 mm. Both sizes confirm that the surface roughness on the tip is much lower than the reference.

Atomic Force Microscopy - AFM

Measurements on the nanometer-scale with the AFM can give an accurate result as to the surface roughness as well as an exact visual image of the topography.

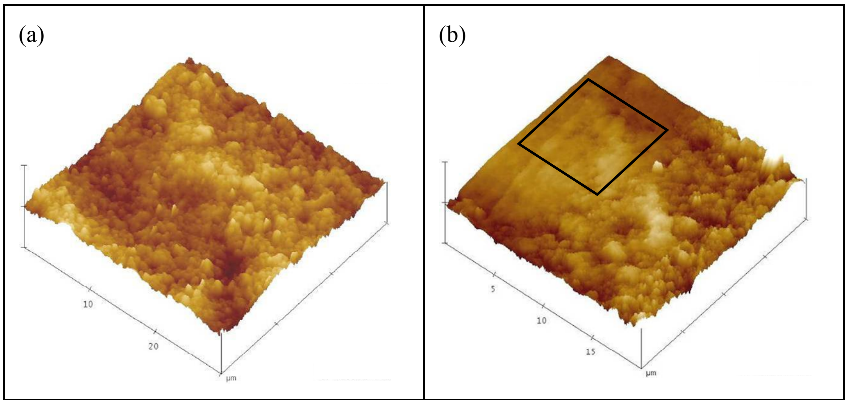

Figure 9 AFM results from the raw material (a) and the tip of the liner (b). The glossy area (black square) is distinguishable and can be separated from the beginning valley.

The images in Figure 9 are topography plots. Image (a) represents the raw material (reference) and (b) a measurement on the tip. The reference illustrates an uneven random surface, but the tip image is separated into a polished and a non-polished zone. Image (b) points out that the surface roughness has to be measured exactly on the surface spot to get accurate values. Measuring in a mixed zone or even missing the polished area leads to false values. The same problem occurred during the MicroProf® measurements. Through zooming into the polished spots, the standard deviation is minimized. The result for image (b) in surface roughness, Rq, in the polished area is 34.95 nm (black squared) as compared to 92.10 nm for the full-image.

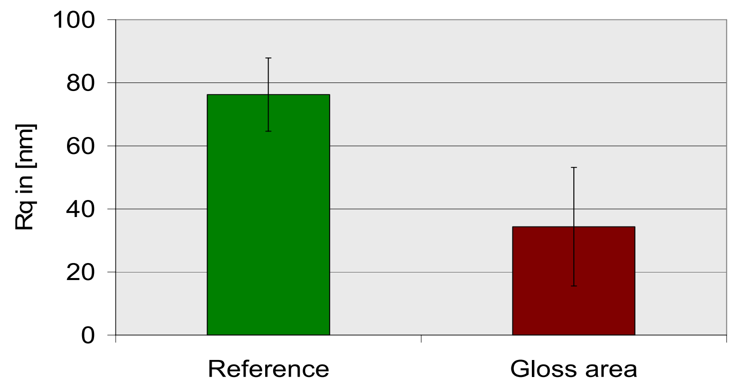

Figure 10 Average values from the AFM analysis. Raw material (reference) compared to the treated sample S4c. The gloss area is on the tip of the corrugated board and shows a drastically lower surface roughness.

Due to problems with the measurement head of the AFM running on coated liners, irregularities in images larger than 10 µm always lead to unusable data for evaluations. It was presumed that particles on the coated surface were attached on the measurement head and caused this error. Therefore, capturing larger areas and picking out the polished spot is not an option. Images with a size of 5x5 µm were perfect and without distortions, but it is more complicated to aim the scanning on the right spot. The result of the analysis using these images is presented in Figure 10. As expected, the same result as with the previous measurements was delivered.

Evaluation of printed samples

The print image analysis, which was carried out in order to discover if gloss pattern appears in the print, the same way as on the unprinted board, was performed with the uncoated quality 2u175 from the laboratory trial and the coated sample S4c from the pilot trial 2. Figure 11 (a) illustrates the uncoated printed sample 2u175 in the 70% halftone. Due to the limited printing width of the single tone areas (15 mm) it was not possible to capture a 3x3 image matrix. Therefore only a single image was taken showing one visible gloss line. As described before, the gloss line distribution is not uniform. Most of the tip lines didn't show any gloss effect and the same result appeared in the printed uncoated samples. An explanation for the lack of gloss effect is that in contact with the uncoated liner surface, the ink will be absorbed in the fiber structure without building any continuous ink film.

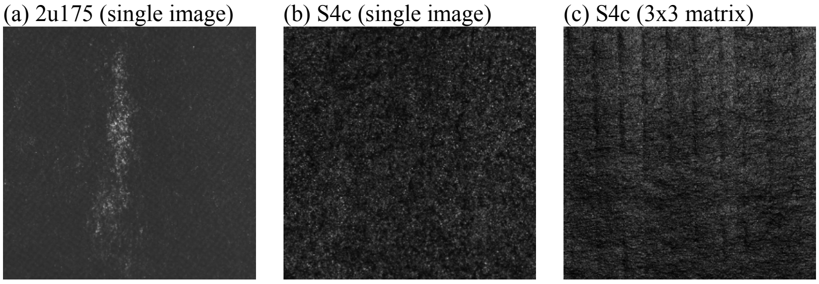

Figure 11 Gloss images of printed samples.
(a) sample 2u175 (lab-test), flexo printed, 70% halftone area
(b) sample S4c (pilot trial 2), flexo printed, fulltone area
(c) sample S4c (pilot trial 2), ink-jet printed, fulltone area

The same measurement on the coated sample delivers a complete different result. The unprinted samples show rather large gloss lines. As described in the Methods chapter, two different printing methods are used: flexo and ink-jet. The samples, printed with both techniques, are shown in Figure 11 (b) and (c). Both images are without any gloss in the form of stripes. With flexo as well with ink-jet, the print arises the gloss to the same saturation level on glossy as well as on non-glossy parts of the coated samples. In this way the ink-gloss is hiding the gloss variations of the unprinted surfaces. In image (c) only the shadows of the flutes are visible but no gloss lines. Therefore, it can be concluded that gloss, influenced by polished areas on the liner in the form of stripes, does not result in print defects neither with flexo nor with ink-jet print.

Conclusions

Paper-metal friction is the keyword and some of its impacts regarding corrugated board production are described in the previous chapters. Friction has less influence on uncoated liners compared to coated liners when it comes to surface roughness and gloss changes. The coating surface is thus more deformable and sensitive to heat and friction. Even standard settings of the corrugator led to damages of the coating surface. Damaged or polished areas of the coated liners in form of gloss lines were visible even without any equipment. The gloss measurements confirmed this and showed that uncoated liners did not have any gloss effects at all. Furthermore, the production speed of the corrugator had the highest impact of the studied factors. All other sample points showed gloss raising effects, but not to the same degree as the sample generated at low speed (50m/min). Reasons for defects in low speed might be overheating of some sections of the corrugator and in that respect overheating of the paper.

The results of the comparison between the laboratory and the full scale trials are correlating. The difference between the polished glossy areas and the reference indicates a decrease in surface roughness on the glossy spots.

Due to some reflection problems, it was not possible to use CLSM to evaluate the coated samples on the polished areas and therefore FRT MicroProf® and AFM were chosen for the study. Furthermore, AFM measurements with images larger than 10µm created distortions caused by measurement head problems.

The aim of the printing trial was to show to what extent the surface roughness influences the printed surface. None of the printing methods, i.e. flexo and ink-jet, showed any final gloss effect referable to the substrate surface and its gloss lines. The explanation has to be separated for the cases uncoated and coated. The uncoated flexo-printed sample prepared in the lab showed a non-uniform gloss line pattern similar to the unprinted state. The reason for the non-changing gloss after the print is probably the lack of capability of the ink to create a uniform layer on a rough uncoated paper surface. On the coated surfaces, on the other hand, the ink is capable in forming an ink film layer on top of the surface of the paper. This film will cover the micro roughness of the matt parts of the paper and thereby creating a homogenous glossy appearance.

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