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Influence of dwell time and temperature on the measured gloss of printed UV-inks containing aluminum pigments

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Abstract This study investigates the relationship between measured gloss and the microstructure of printed UV-inks containing aluminum pigments. Using a laboratory flexo printing machine, UV-inks containing leafing-type vacuum metallized pigments were printed onto Chromolux paper and primed MultiArt Gloss paper. The time between printing and curing of the ink (dwell time) was varied between the experimental runs. For some samples, hot air was applied onto the uncured UV-ink during the dwell time. The influence of heat (hot air) and dwell time on gloss and the topography of the pigment layer as well as the influence of the substrate was investigated. Roughness and waviness data were obtained using a confocal microscope (Sensofar PLu Neox), gloss measurements were obtained using an IQ-S gloss meter. It was shown that a longer dwell time as well as hot air has a positive influence on the specular gloss measured on the metallic ink printed on Chromolux paper. Also, good correlations could be found between specular gloss, roughness, and waviness, respectively. For primed Multi Art Gloss paper, however, a longer dwell time and hot air can have a negative influence on specular gloss. Also, correlations between roughness, waviness and specular gloss are not as strong as for Chromolux paper.

Keywords Aluminum pigments, Roughness, Waviness, Confocal microscopy, Gloss

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Introduction and theory

In the label and package printing industry, many different printing methods are in use for the production of metallic embellishments.[1] One of them is the use of UV-curable inks containing aluminum pigments that can be applied on a substrate by printing. On the market, different pigment types can be found that are dispersed in printing inks. These are cornflake pigments, silver dollar pigments, and vacuum metallized pigments (VMPs).[2,3] With the use of VMPs, a high gloss and a mirror-like appearance can be achieved, since this kind of pigment is especially thin and has a very smooth surface. This reduces the scattering of light on the surface of the pigments. VMPs require a complex production process leading to high costs. Hence, special attention is paid on yielding a metallic embellishment of high gloss and on harnessing the full potential of VMPs in terms of gloss and mirror-like appearance. When producing metallic embellishments, often a flexo printing unit is used to print UV-curable inks with metallic pigments on a substrate. Aluminum pigments dispersed in solvent-based inks yield the highest gloss, since here pigments do not have to be encapsulated to prevent a chemical reaction between the aluminum and solvent.[4] However, solvent-based inks require expensive explosion protection measures on the printing machine and are increasingly avoided due to environmental aspects. If using water-based or UV-curable inks, no explosion protection measures are needed. However, water-based inks often do not lead to satisfying results in terms of gloss because encapsula-

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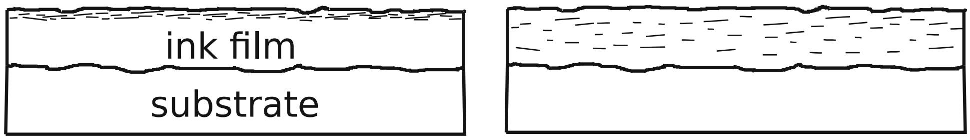

Fig. 1: Distribution of leafing (left) and non-leafing (right) aluminum pigments in ink. In the left, pigments float up to the ink film surface after printing. In the right, they stay evenly distributed in the ink. In this study, using VMPs in UV-inks, we are faced with the left situation

tion of these pigments is needed to prevent chemical reactions between water and aluminum. This encapsulation leads to a greater scattering of light and therefore a lower gloss. Aluminum pigments in UV-inks also require a treatment to prevent UV-initiators in these inks to react before exposure to UV-light. However, they can still reach satisfying results in terms of gloss.

Due to their treatment, today VMPs dispersed in UV-inks are commercially available as leafing pigments only.[5] This means, that these pigments float to the top of the ink film after printing as opposed to non-leafing pigments. The difference of leafing and non-leafing properties is shown schematically in Fig. 1.

After printing the ink onto a substrate, the gloss of the ink film changes with time due to primarily three effects: Firstly, the ink film smooths out after printing. Secondly, the ink interacts with the substrate. For instance, if ink absorptive paper is used, the binder of the ink partially penetrates into it. Thirdly, the leafing pigments float on the top of the ink film. The change of gloss of an uncured or not yet dried ink after printing is called 'dynamic gloss.' Investigations on the dynamic gloss of ink films not containing metal effect pigments have been conducted by Koivula et al.,[6] Preston et al.,[7–9] Silvennoinen et al.,[10] Kitano et al.,[11] and Jeon.[12] First investigations on dynamic gloss using metallic printing inks were carried out by Weber et al.[13]

The distribution and orientation of metal effect pigments in ink as well as the regarding appearance-microstructure relationships have been investigated intensively for automotive coatings. According to Kirchner and Houweling[14] and Seubert et al.,[15] originally, investigations on the distribution of metal effect pigments in ink films were carried out by analyzing cross-cuts through the substrate and ink film. However, this technique does not allow for capturing the orientation of the flakes in all three spatial directions. Furthermore, producing cross cuts is very time consuming. Hence, other analytical methods, for example confocal microscopy, are used that allow for non-destructive analysis of metal effect pigments in ink layers. Kettler and Richter[16] used goniospectrophotometry, confocal laser-scanning microscopy, and microscopic image analysis of basecoat cross-cuts to examine the interrelation between the orientation of platelet-like effect pigments in surface coatings and their coloristic properties. Sung et al.[17] made investigations on metallic coatings and addressed the flake orientation and flake surface roughness on the distribution of the light scattered by the coatings. Topographic maps of the flakes in the coating were obtained using laser scanning confocal microscopy. Kirchner and Houweling[14] used laser scanning to investigate a set of 117 metallic samples produced with different metallic inks containing pigments with cornflake and silver dollar shapes. An investigation on the flake orientation distributions was conducted and it was quantified that large flakes orient better compared to small flakes. Seubert et al.[15] used samples with metallic paints to explore microstructural parameters of platelet-coating systems that control the appearance. Data obtained with laser-scanning confocal microscopy was compared to the lightness (L*) measured 15° off specular. It was found that the orientation of the platelets is a major parameter that influences the brightness. Furthermore, beneath the orientation, the size of the gaps between the pigments—the gap factor—affects the scattering behavior of the system.

The concern of this paper is to link studies of dynamic gloss with studies investigating appearance-microstructure relationships of metal effect pigments in ink. We produced sample sets printed with metallic UV-ink containing VMPs on two different paper substrates. The ink was cured after different time intervals subsequent to printing what leads to different microstructures and optical properties depending on the time interval, also called dwell time. For two sample sets, heat was induced to the printed ink film. As stated by Olsson et al.,[18] the viscosity of printing inks declines with increasing heat. This effect impacts the behavior of the ink and the aluminum pigments inside it and affects the gloss of the printed samples.

Gloss measurements carried out in this paper include specular gloss measured in gloss units (GU), distinctness-of-image gloss (DOI) measured in percent, and haze measured in haze units (HU). The measured specular gloss corresponds to the perceived surface brightness associated with the specular reflection of a surface.[19] The measured DOI corresponds with sharpness of images of objects produced by reflection at a surface, while a DOI of 100% results from a flat surface with mirror-like reflections.[19] The haze describes the diffuse scattering of light at a surface that leads to an apparent reduction in reflections and a milky appearance.[20] Haze is a measure for the scattering of light on a surface and therefore a measure for the milky appearance of the reflected image. Specular gloss is mostly considered in industry if surface gloss is of interest. In this case, measurements at the angle of 60° is mostly preferred and is common practice for comparing specimens. Specular gloss measurement at

20° is advantageous for comparing high gloss specimens with 70 GU or higher.[21] According to ASTM D523-14,[21] apertures with different sizes are placed in front of the photodiodes measuring the reflected light flux. For the reason that the aperture in front of the photodiode at 60° is much larger than the aperture in front of the photodiode at 20°, minor waviness at the reflecting surface affects the specular gloss measured at 20° much more than specular gloss measured at 60°.[13] Gloss meters are calibrated in a way that they measure a specular gloss of 100 GU at all angles on a polished black glass calibration tile. Hence, dielectric materials with a refraction index similar to the black glass tile or a smaller one, cannot reach specular gloss values higher than 100 GU at any angle. Measurements on metallic surfaces, however, can lead to much higher specular gloss values. The measurement range for the specular gloss meter used in this study is 0–2000 GU at the angle of 20° and 0–1000 GU at the angle of 60°.[22] 2000 GU at 20° and 1000 GU at 60° would be feasible on a perfectly reflecting mirror. Due to the smaller increments for differences of the reflected intensity for the specular gloss measured at 20°, measurements on flat metallic surfaces can result in specular gloss values higher than those measured at 60°. If the metallic surface is rough, even slightly scattered light will not pass through the small aperture at 20°. In this case, the specular gloss measured at 60° is mostly higher.

Materials and methods

All gloss measurements in this paper were made using an IQ-S gloss meter (Rhopoint Instruments, UK). This instrument is suited for the measurement of specular gloss at 20°, 60°, and 85°. Besides that the gloss meter also measures DOI and haze. On each sample, ten gloss measurements were made: five in and five perpendicular to printing direction.

A laboratory flexo printing machine IGT F1 (Printability Tester F1, IGT Testing Systems, Netherlands) was used for the printing trials. The print settings of the printing machine as well as the anilox rollers used for the experiments are listed in Table 1. For the printing trials, no rasterization of the flexo plate was used as all samples were printed with full surface area.

Table 1: Print setting of the laboratory flexo printing machine IGT F1

Anilox force	60 N
Printing force	70 N
Printing velocity	0.50 m/s
Anilox roller volume for printing metallic inks	16 mL/m^2
Anilox roller volume for printing primer	8 mL/m^2

The two substrates used in the experiments were Chromolux paper (Zanders, Germany) with a grammage of 100 g/m^2 and MultiArt Gloss paper (Papyrus, Germany) with a grammage of 300 g/m^2. In the printing industry, Chromolux paper is used to produce high quality products of very high gloss with a mirror-smooth surface as, for example, promotional posters. Even without imprinted aluminum pigments it already has a high specular gloss value of about 80 GU measured at 60° and 55 GU measured at 20° with an IQ-S gloss meter. MultiArt Gloss paper on the other hand is a standard illustration printing paper which is commonly used for all kinds of print jobs that require results of medium to high gloss qualities. Without primer it has a specular gloss of about 33 GU measured at 60° and 10 GU measured at 20°. With imprinted primer it has specular gloss values of 35 GU measured at 60° and 10 GU measured at 20°.

Only the MultiArt Gloss paper was primed prior to the metallization because the application of primer is a common procedure in the printing industry. For the reason that Chromolux paper already has a very smooth surface, normally no primer is applied. The UV-primer used for the experiment was provided by the company Schlenk (Carl Schlenk, Germany). The metallic printing ink used for this study was a UV-curable low-migration printing ink, which was also provided by Schlenk. According to the datasheets and additional company information, the pigments of the ink containing VMPs have a d_{50} size of 7 μm and a d_{99} size of 10–12 μm, the ink has a metal content of 12.2% and a viscosity of 300 − 900 mPas. In order to cure the inks, a UV-lamp (Beltron, Germany) came to use. The used lamp has the advantage that the UV-light source is behind a shutter that can be opened at a desired point in time. For some of the trials the ink was heated between printing and UV-curing. To do so, an ELECTRON ST hot air blower (Leister, Germany) was used that generates adjustable hot air. For the distance between the hot air blower and the samples used in the experiment, a temperature of about 50 °C was measured on the samples during hot air blowing using a PeakTech 4960 infrared thermometer (PeakTech, Germany). The used laboratory printing machine, hot blower, as well as the set-up for curing the UV-ink are shown in Fig. 2.

For the investigation of the influence of dwell time and to study the influence of the temperature on the flakes in the printing ink, four series of experiments were conducted: two of them on Chromolux paper and two on the primed MultiArt Gloss paper. For one series of each substrate, hot air blowing came to use. After the metallic inks were printed, a piece of the printed paper was cut out from the substrate. Afterward, the ink layer was cured with the UV-lamp. In the case of the investigation of the influence of hot air, the hot air blower was switched on before printing and held at a distance of approximately 20 cm from the

Fig. 2: Set-up for UV-curing (left), hot air blower (middle), and laboratory flexo printing machine IGT F1 (right) used in the experiment

sample after printing. Ten seconds before UV-curing, the heating was stopped to place the sample in the UV-curing set up. The time between printing and curing was measured with a stopwatch. The two series printed on Chromolux paper consisted of six samples each. The time between printing and curing was between 30 and 180 s in steps of 30 s. The series printed on MultiArt Gloss paper without the use of hot air also consisted of six samples. However, the time between printing and curing was 10 s, 20 s, 30 s, 60 s, 90 s, and 120 s. The reason for this choice was that due to pretests it was assumed that for this paper type the greatest changes would occur directly after printing in the time interval until 30 s. The series printed on primed MultiArt Gloss paper with the use of hot air consisted of four samples only. The time between printing and curing for those was 30 s, 60 s, 90 s, and 120 s. For the primed MultiArt Gloss paper substrate no tests with longer periods than 120 s after printing were taken into account because during the experiment no visible changes in terms of gloss could be observed beyond that time interval.

For the analysis of the gloss of the samples, the IQ-S gloss meter was used. For the analysis of the gloss of the samples, mainly the specular gloss measured at 20° and 60° were used. For the analysis of the pigment layer topography and pigment distribution in the ink layer, the confocal microscope Sensofar PLu Neox (Sensofar, Spain) with a Nikon EPI objective with 50x magnification, a working distance of 0.35 mm, and a numerical aperture of 0.95 was used. The numerical aperture determines the largest slope angle of edges on the surface. A high numerical aperture is especially important for the investigation of overlapping metallic flakes at different heights as these lead to high slope angles. For each sample, five areas with a size of 340 × 283 μm^2 were scanned with a resolution of 0.28 μm/pixel. A depth scanning range of 16 μm was chosen with a step size of 0.10 μm. Two filter techniques were applied to the data to determine the desired surface characteristics. These were the shape-removal operator and the ISO 25178 filter. Using those, roughness and waviness parameters from the topography data of the pigment layers could be obtained. Roughness data of the topography were obtained using the ISO 25178 filter with cut-offs of λ_S = 2.50 μm and λ_C = 0.08 mm.

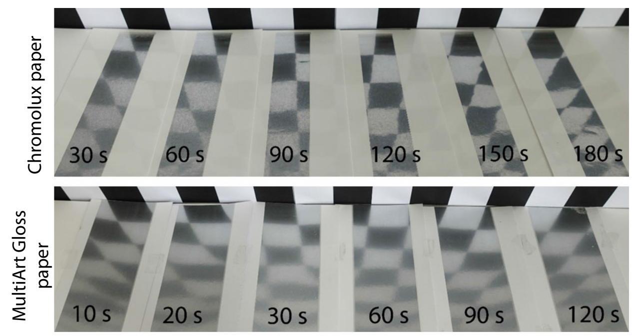

Fig. 3: Series of samples printed on Chromolux paper and MultiArt Gloss paper. The dwell time is indicated on the samples. No hot-air was used during the dwell time of the samples shown here

Waviness data were obtained by using the ISO 25178 filter with a cutoff of λ_S = 0.08 mm. From these data the root mean square height of the area (*Sq*), which is the standard deviation of the height distribution was used to compare the roughness and waviness of the samples.[23]

Results and discussion

Figure 3 shows the samples of the series printed on Chromolux paper and primed MultiArt Gloss paper without additional heat during the dwell time. To give an impression of the glossiness and mirroring capability of the samples, the picture was taken with the samples placed in front of a checkerboard. With the samples printed on Chromolux paper it can be seen that the reflection of the checkerboard gets clearer with increasing dwell time. This is not the case with the samples printed on primed MultiArt Gloss paper. No noticeable differences can be seen between these samples.

The results of the specular gloss measurements at 20° and 60° on the series printed on Chromolux paper with and without the use of hot air during dwell time are shown in Fig. 4. The black horizontal dashes in the graph denote the mean of the ten gloss measurements made on each sample. The purple area shows the

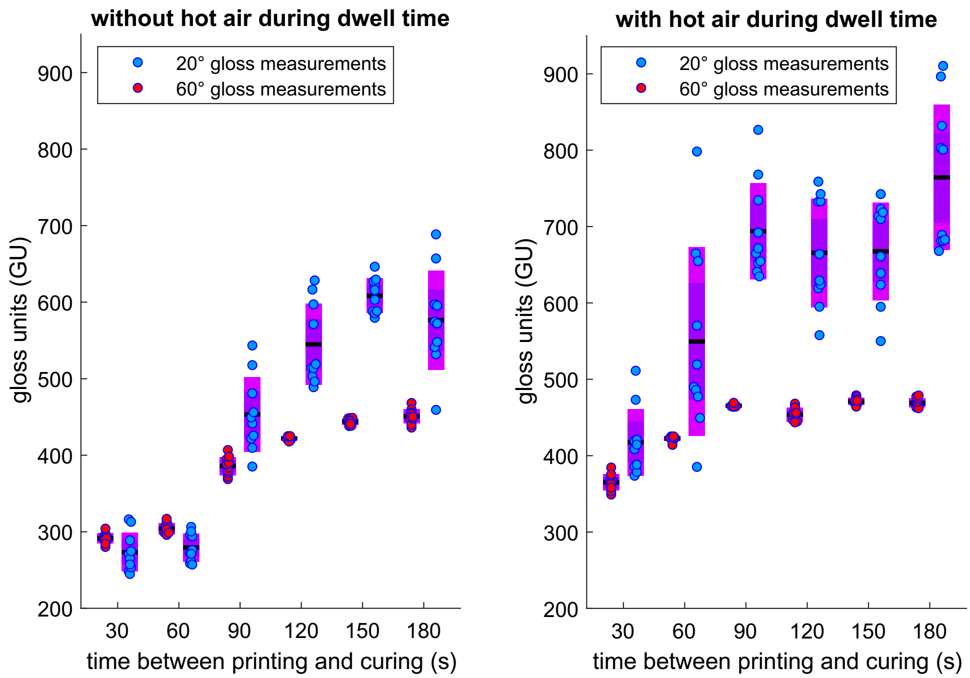

Fig. 4: Specular gloss (20° and 60°) measured on the series printed on Chromolux paper. Purple areas: standard error of the mean, pink areas: standard deviation

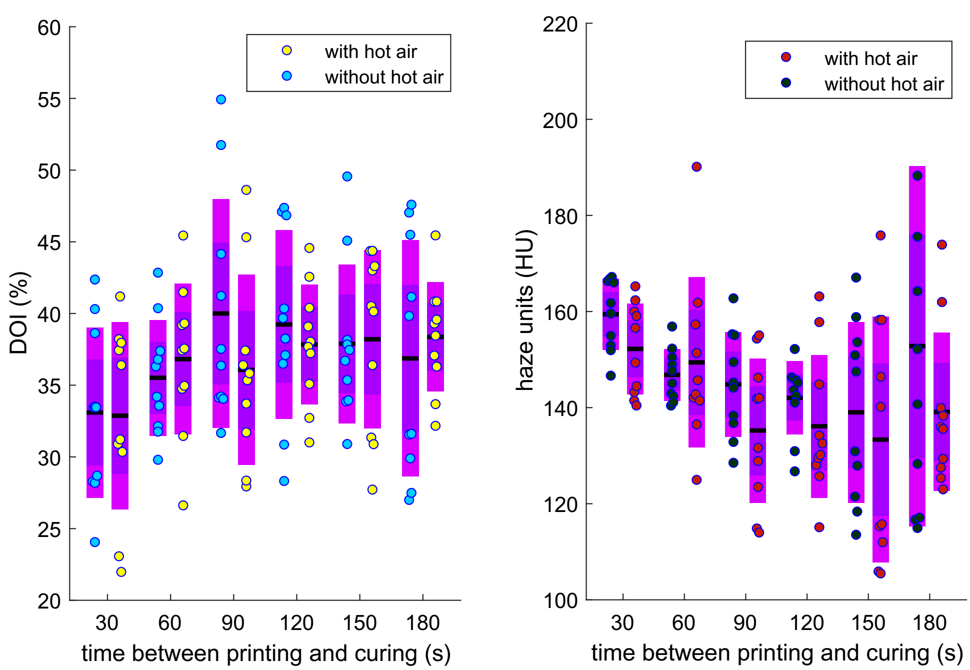

Fig. 5: Measurements of DOI and haze on the samples printed on Chromolux paper with and without the use of hot air. Purple areas: standard error of the mean, pink areas: standard deviation

standard error of the mean (SEM), and the pink area shows the standard deviation (SD). Figures 5 to 8 are generated using the notBoxPlot function in MatLab.[24]

From the comparison of the two graphs in Fig. 4, it can be seen that the application of hot air during dwell time strongly influences specular gloss. It can be seen that a strong increase in specular gloss measured both at 20° and 60° takes place between 30 s and 90 s after printing. The greatest differences in both graphs can be seen in the comparison between the specular gloss measured at 20°. For the samples exposed to hot air during dwell time, specular gloss measured at 20°

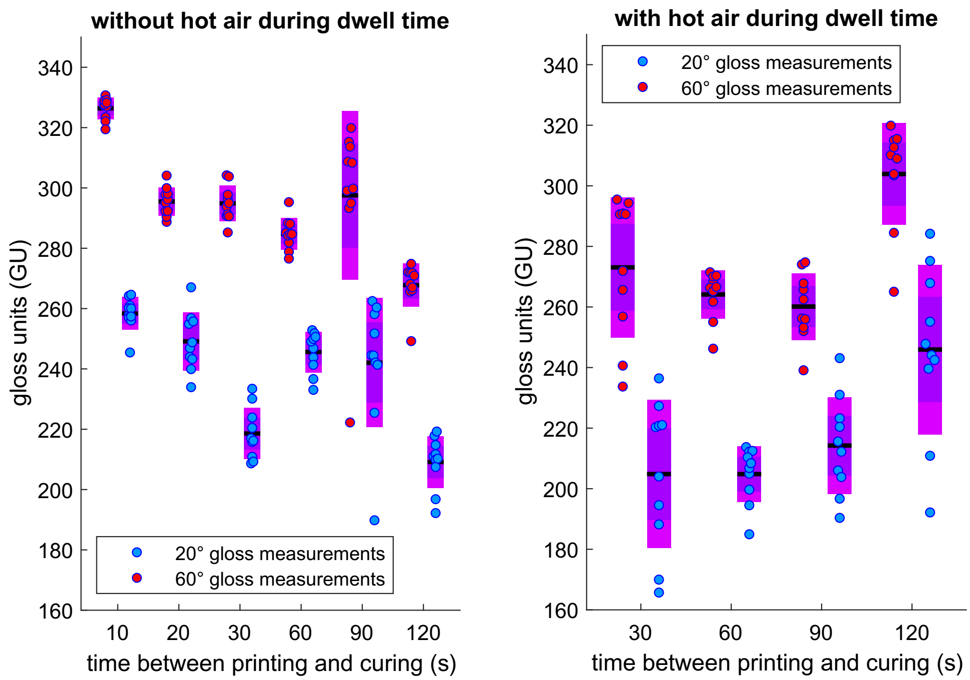

Fig. 6: Specular gloss (20° and 60°) measured on the series printed on primed MultiArt Gloss paper. Purple areas: standard error of the mean, pink areas: standard deviation

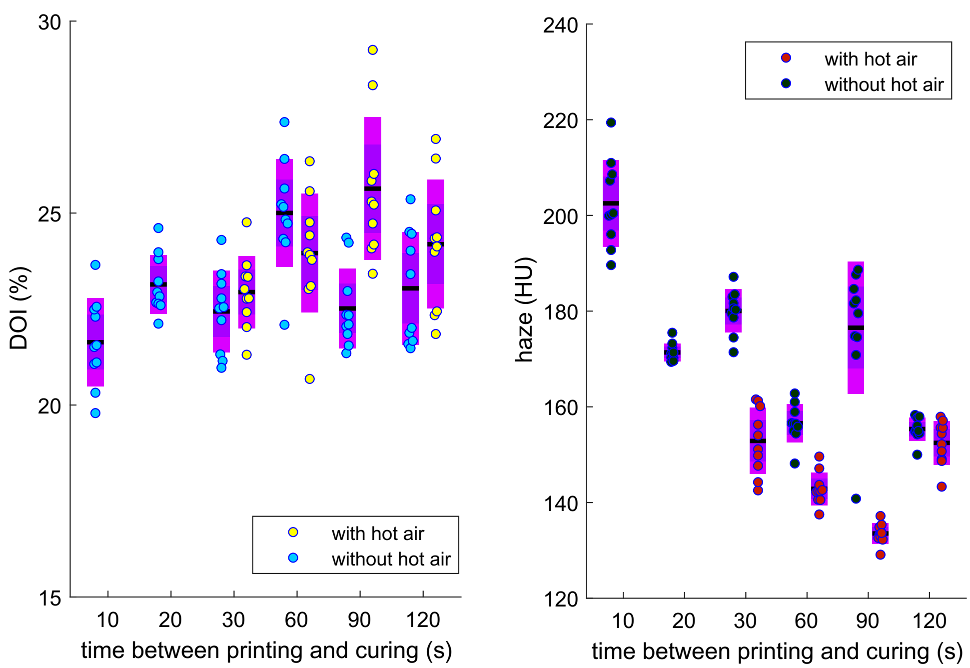

Fig. 7: Measurements of DOI and haze on the samples printed on primed MultiArt Gloss paper with and without the use of hot air. Purple areas: standard error of the mean, pink areas: standard deviation

reaches a mean of up to 764 GU. In comparison, for samples not exposed to hot air during the dwell time, specular gloss measured at 20° only reaches a maximum mean of 608 GU. For most of the samples printed on Chromolux paper, the longer the time between printing and curing, the higher the specular gloss.

It is striking that the variation of the ten gloss measurements on each sample is much higher for

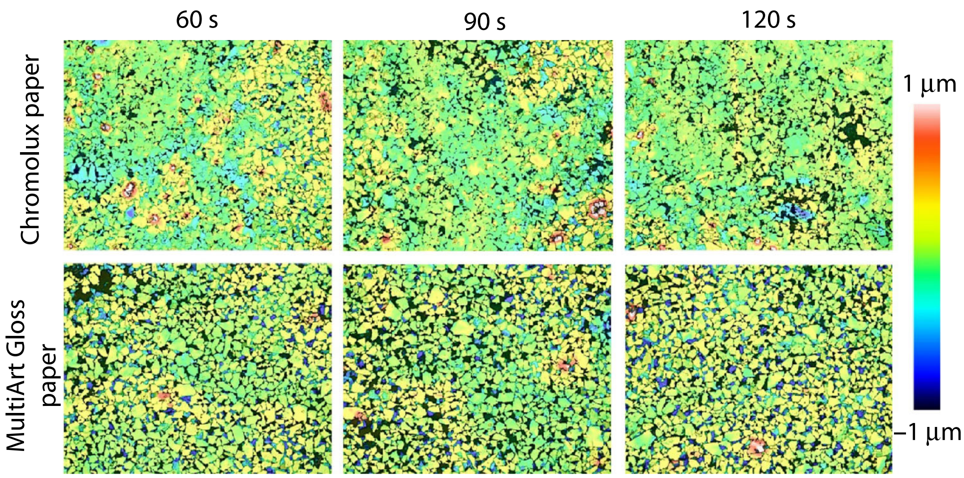

Fig. 8: Confocal images of samples cured after different time intervals selectively filtered for roughness. Each image has a size of 260 μm × 200 μm

specular gloss measurements at 20° compared to specular gloss measurements at 60°. Also the variation of specular gloss measured at 20° is higher for samples produced with hot air than those produced without hot air. The mean of the relative standard deviations of the ten specular gloss measurements at 20° is 8.6% over all samples produced without hot air and 12.5% for samples produced with hot air. However, the mean of the relative standard deviations of the ten specular gloss measurements at 60° is only 1.9% for the samples produced without hot air and 1.4% for samples produced with hot air. The main reason for the variation between the standard deviations of specular gloss measured at 20° and 60° is that the receiver apertures of a gloss meter at the angles of 20° and 60° differ in size as described in ASTM D523—14.[21] For the reason that the aperture at 20° is much smaller, small ripples on the sample surface effect the direction of the reflected light ray in a way that for some measurements not the biggest part of the reflected light enters the receiver, which is especially the case for high reflective surfaces.

In Fig. 5, the respective measurements of DOI and haze for samples printed on Chromolux paper are shown. Interestingly, the DOI does not follow the significant rising trend of the specular gloss measured at 20° and 60°. The mean values of the DOI stagnate between 33 and 38% for the samples produced without hot air during dwell time. For the samples produced with hot air during the dwell time, the DOI stagnates between 33 and 40%. In the right graph of Fig. 5, it can be seen that the haze slightly decreases for both samples printed with and without hot air for the intervals of 30 to 150 seconds between printing and curing. For the last interval of 180 seconds dwell time, however, a slight increase in haze is found. However, also for the haze the trend is not very significant and significant statements could only be made with measurements on additional samples.

As shown in Fig. 6, for the series printed on primed MultiArt Gloss paper different effects can be seen. First, it is striking that the specular gloss results measured at 20° is consistently smaller than those measured at 60°. Further, contrary to the samples printed on Chromolux paper, the use of hot air does not necessarily lead to higher results of specular gloss. While for the samples produced without the use of hot air during the dwell time a decreasing trend in specular gloss for longer time intervals between printing and curing can be seen, for samples produced with the use of hot air an increasing trend of specular gloss for longer dwell times can be noticed.

In Fig. 7, the measurement results of DOI and haze on the samples printed on primed MultiArt Gloss paper are shown. It can be seen that the DOI measurement results follow no clear trend. The haze follows a slightly decreasing trend with a longer dwell time for both samples produced with and without hot air.

The gloss measurements show that an increased dwell time leads to a higher gloss for samples printed on Chromolux paper. However, this is not necessarily the case for primed MultiArt Gloss paper. One reason for this could be the difference in roughness between the two substrates. The higher roughness of the primed MultiArt Gloss paper could hinder the ink film from leveling out unevenness after the printing process. Another reason could be differences in the ink absorption properties of the substrates. A higher absorption rate would diminish the mobility of the pigments after printing. A further reason could be differences in the surface energy of primed MultiArt Gloss paper and unprimed Chromolux paper. It is possible that the primer reduces the surface energy of

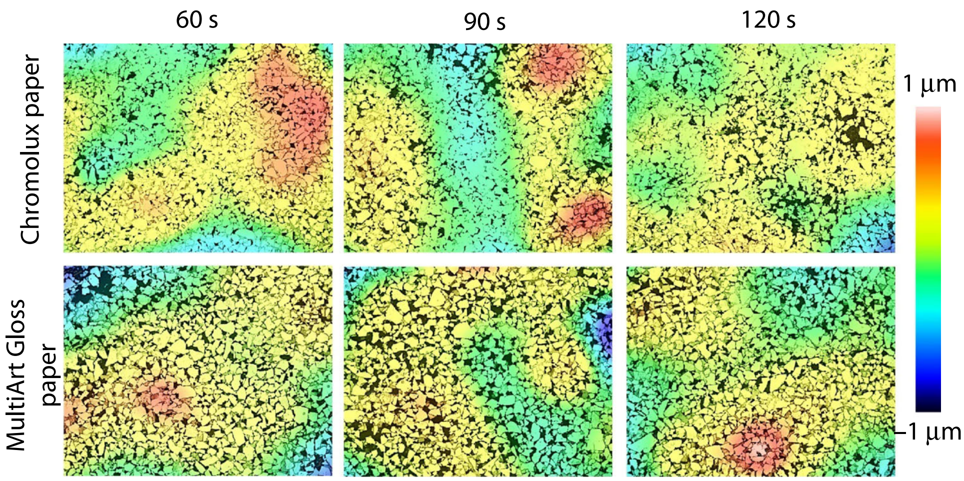

Fig. 9: Confocal images of samples cured after different time intervals selectively filtered for waviness. Each image has a size of 260 µm × 200 µm

the paper and hence reduces the wet-out of the printing ink. The positive impact of hot air during dwell time could be explained with a decreasing viscosity of the printing ink with increased temperature what could increase the mobility of the leafing pigments and hence to a better alignment between them.

Figure 8 shows the filtered roughness of the pigment layer topographies on the two different paper types. The roughness data obtained are mainly influenced by height differences and tilting between neighboring pigments in the layer. For the reason that structures smaller than 2.5 µm are filtered out, surface roughness of the pigments does not play a role. The confocal microscope images show that pigments on Chromolux paper are much better aligned to each other than pigments on MultiArt Gloss paper. The black areas in the images correspond to points where the angle of light reflection was out of the aperture of the confocal microscope. No data could be obtained from here by this method. Hence, these areas do not contribute to the roughness or waviness parameters that could be calculated from the data. It can be seen that the changes in the appearance of the pigmented layer are only marginally changing with dwell time. However, considering the relevance of these images with respect to roughness and waviness features, it should be noted that they are of very small size compared with the measuring spot in the gloss meter, which is more than a magnitude greater than the microscope images. Hence, our confocal images cannot significantly explain the measured or visual gloss of the samples.

In addition to roughness, which was selectively filtered in the data shown in Fig. 8, specimen waviness could also affect gloss measurements because it also causes light scattering. The same areas of the samples shown in Fig. 8 but filtered for the waviness are shown in Fig. 9. The waviness data are affected by unevenness of larger scales. These larger scale irregularities could be attributed to an unevenness of the substrate itself, or to irregularities in the applied ink film.

The relative standard deviations of the Sq roughness and Sq waviness obtained from the five confocal images of every sample is rather high. The mean relative standard deviation of the Sq roughness of all samples printed on Chromolux paper is 26.7%. The mean relative standard deviation of the waviness of these samples is 30.8%. For primed MultiArt Gloss paper the mean relative standard deviation of the Sq roughness is 26.0%, while the mean relative standard deviation of the Sq roughness amounts to 13.9%.

For each sample set it was checked to which extend roughness and waviness data of the topography of the pigment layer correlates with the measured specular gloss measured at 20° and 60°. In Fig. 10, the gloss vs the Sq roughness and Sq waviness data of the samples printed on Chromolux paper without and with hot air during the dwell time are shown. Table 2 shows that there is a significant correlation between the topography parameters and specular gloss.

Interestingly, as can be seen in the left graph of Fig. 10, the sample with the smallest mean Sq roughness of only 0.062 µm was made without the use of hot air during the dwell time. In terms of specular gloss, however, it does not exceed the sample with the highest specular gloss that was made with the use of hot air during dwell time. The same observation also accounts for the right graph comparing Sq waviness and specular gloss. This means that the measured confocal data and the parameters of Sq roughness and Sq waviness retrieved thereof do not reveal the full picture about the measured gloss parameters.

In Fig. 11, the gloss vs the Sq roughness and Sq waviness data of the samples printed on primed

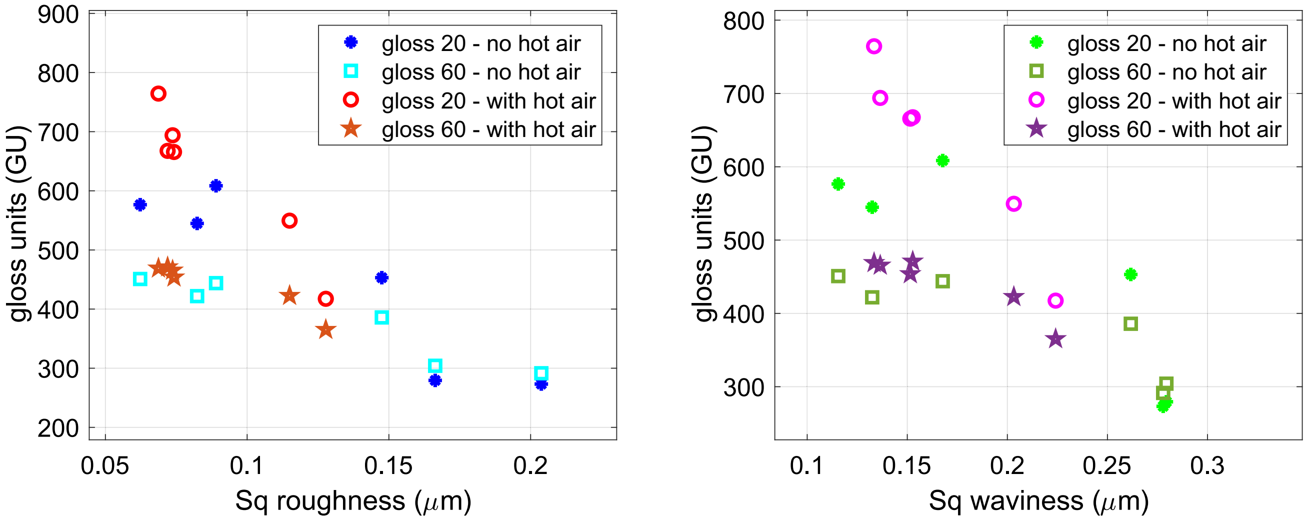

Fig. 10: Mean Sq roughness and waviness data obtained with the confocal microscope on Chromolux paper on the *x*-axis and mean specular gloss measurement values measured at 20° and 60° on the *y*-axis for samples produced with and without hot air

Table 2: Pearson correlation coefficients between measured specular gloss values and measured Sq roughness and Sq waviness values on Chromolux paper imprinted with metallic ink

	Specular gloss angle	Correlation with Sq roughness	Correlation with Sq waviness
No hot air	20°	−0.9346	−0.8804
No hot air	60°	−0.9523	−0.8888
With hot air	20°	−0.9534	−0.9723
With hot air	60°	−0.9487	−0.9405

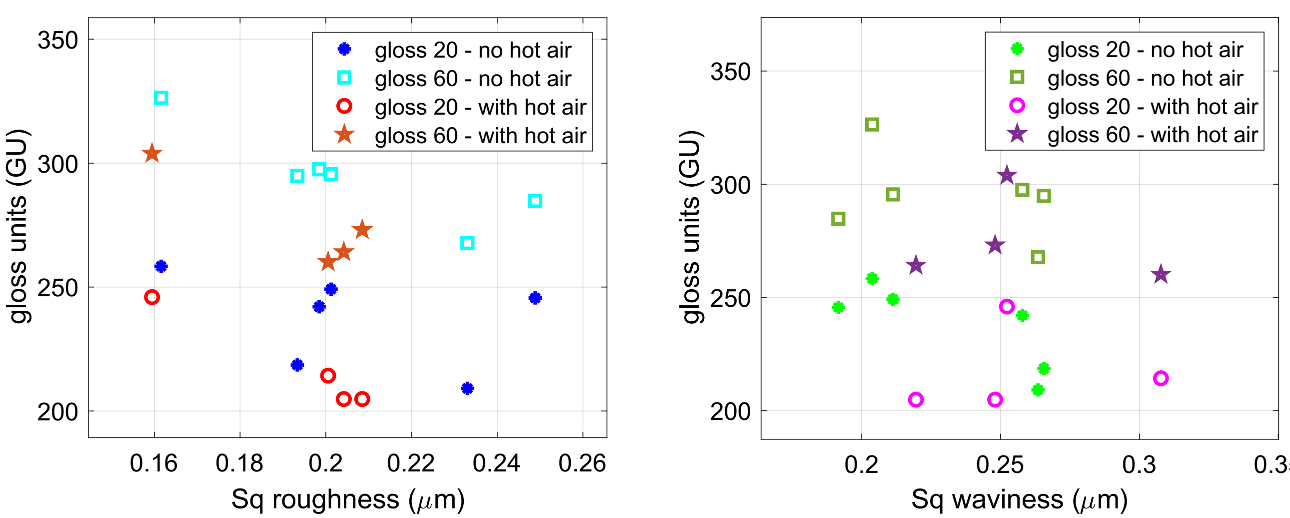

Fig. 11: Sq roughness and waviness data obtained with the confocal microscope on primed MultiArt Gloss paper imprinted with metallic ink paper on the *x*-axis and gloss measurement values measured at 20° and 60° on the *y*-axis for samples produced with and without hot air

MultiArt Gloss paper with and without the use of hot air during dwell time are shown. When comparing the Sq roughness and Sq waviness parameters with specular gloss of primed MultiArt Gloss paper imprinted with metallic inks, it stands out that the relation between surface parameters, and specular gloss is not

Table 3: Pearson correlation coefficients between measured specular gloss values and measured Sq roughness and Sq waviness values on primed MultiArt Gloss paper imprinted with metallic ink

	Specular gloss angle	Correlation with Sq roughness	Correlation with Sq waviness
No hot air	20°	−0.4061	−0.8013
No hot air	60°	−0.8737	−0.3969
With hot air	20°	−0.9911	0.1345
With hot air	60°	−0.9137	−0.2124

that clear for the individual sample sets as for the samples with Chromolux paper as a substrate. The correlations between gloss, Sq roughness, and Sq waviness, respectively, are shown in Table 3. Generally, the correlations are lower than for Chromolux paper. The samples printed with the use of hot air during dwell time yield a high correlation between measured gloss and roughness. However, these series consist of only four samples, which increases the possibility of a random correlation. As for the samples printed on Chromolux paper it can be observed that the Sq roughness and waviness parameters do not reveal the full picture about the specular gloss. For instance, the sample with the highest mean specular gloss measured at 60° reaches 326 GU. Its mean Sq roughness is 0.162 µm. The sample with the smallest mean Sq roughness of 0.159 µm only reaches 304 GU. Its waviness, however, is larger than in the first mentioned sample. Maybe a combination of several topography parameters could explain the connection between optical parameters and topography parameters in a more adequate way.

Conclusions and outlook

In this study we showed that when using UV-inks with leafing aluminum pigments for the metallization of paper or primed paper substrates, the dwell time of the ink can have a huge impact on the specular gloss measured on the samples. It was shown that if using Chromolux paper, a high dwell time of the ink has a positive impact on the gloss. It is assumed that in this case aluminum pigments have more time to float up and align parallel to the ink film surface. For the Chromolux paper it was also shown that hot air during dwell time has a positive influence on gloss. This positive influence may come from a reduced viscosity of the ink, which might lead to a higher rate of pigments floating to the top of the ink film. For samples printed on primed MultiArt Gloss paper, however, it was shown that a longer dwell time does not lead to a higher gloss and can even lead to a lower gloss. Also the use of hot air does not necessarily improve the gloss. Several parameters can be considered to contribute to this strong influence of the substrate on the gloss. The first and maybe most important parameter could be the roughness of the substrate. It could lead to the effect that the ink in the film gathers in the small wrinkles of the surface. However, the question why specular gloss again increases on the primed MultiArt Gloss paper if hot air is used during the dwell time could not be answered. It can be assumed that beneath surface roughness also water absorptivity and porosity parameters influence the behavior of the ink and the pigments.

The relation between topographic data of the pigment layer such as Sq roughness and Sq waviness and measured specular gloss was investigated. It was shown that roughness and waviness correlate well with measured specular gloss at the angles of 20° and 60° for samples printed on Chromolux paper. For primed MultiArt Gloss paper, however, the correlation between roughness, waviness and gloss are not that high.

In the future, similar experiments will be carried out on more types of paper substrate to understand the influence of the substrate on the gloss better. Further, the temperature on the samples during the heating with hot air will be constantly monitored using a continuously measuring infrared thermometer or a thermal imaging camera. Also, a setup will be used that keeps the distance between the hot air blower and the sample the same for each trial. Additionally, the influence of the heat on the adhesion of the ink on the substrate will be tested and the influence of heat on the viscosity of UV-inks with metal effect pigments will be investigated.

Last, gained knowledge will be applied to an industrial printing machine. Print trails with UV-inks with aluminum pigments with different temperatures of hot air will be conducted to gain knowledge that can be applied in industrial printing processes.

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